SCHOOL OF
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JOINT HIGHWAY RESEARCH PROJECT

FHWA/IN/JHRP-85/13

THE IDENTIFICATION OF AREAS OF ROUTINE MAINTENANCE PRODUCTIVITY IMPROVEMENT: FINAL REPORT

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FINAL REPORT

TO: H. L. Michael, Director
Joint Highway Research Project

FROM: K. C. Sinha, Research Engineer
Joint Highway Research Project

July 2, 1985
Revised August 28, 1985
Project No: C-36-67N

File: 9-11-14

Attached is the Final Report on the HPR Part II Study titled, "Development and Use of a Management Information System to Identify Areas of Routine Maintenance Productivity Improvement." The research work has been conducted by Stephen M. O'Brien under my direction.

An earlier interim report presented the development of a Management Information System (MIS) for evaluating and improving the productivity of routine maintenance operations. This final report presents the results of statistical analysis of the MIS data and field observations. Checklists have been developed that can be used in identifying areas of routine maintenance productivity improvement.

This report is forwarded for review, comment and acceptance by the IDOH and FHWA as fulfillment of the objectives of the study.

Respectfully submitted,

K. C. Sinha
Research Engineer

KCS/rrp

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Final Report

THE IDENTIFICATION OF AREAS OF ROUTINE MAINTENANCE PRODUCTIVITY IMPROVEMENT

by

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Purdue University

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16. Abstract

The interim report on this project (FHWA/IN/JHRP-84-11) presented the development of a management information system (MIS) for evaluating and improving the productivity of routine maintenance operations. The present report examines two specific activities, shallow patching and crack sealing. The statistical analyses that can be undertaken on the data produced by the MIS are described. Results of field observations are discussed and checklists are presented that can be used in identifying areas of routine maintenance productivity improvement.

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HIGHLIGHT SUMMARY

This report presents a method to identify factors that influence shallow patching and crack sealing activities of highway pavement routine maintenance. The following steps were followed in the research.

1. A statistical analysis was conducted of the data produced by the management information system (MIS) developed for the Indiana Department of Highways (IDOH) in the first phase of the study.

2. A questionnaire survey was sent to all subdistricts within Indiana to increase the data base on shallow patching and crack sealing.

3. Field observations were conducted at selected subdistricts throughout Indiana.

4. A set of checklists was developed for shallow patching and crack sealing that can be used by managers and subdistrict superintendents to determine why certain subdistricts have high or low productivity levels.

The procedure followed was defined so that they can be repeated for other routine maintenance activities performed by the Indiana Department of Highways.

CHAPTER 1

INTRODUCTION

1.1 Introduction to Study

Today, if productivity of routine maintenance projects could be increased by one percent (1%), a savings of over $150 million per year could be obtained on a national basis [1]. In order to improve productivity, maintenance management at all levels of a highway agency needs an effective approach to monitor the field activities and a method to determine which factors influence the productivity of each activity performed by maintenance crews.

Taking advantage of computer technology, maintenance management information systems are currently being developed in many states for planning and control of maintenance activities. Indiana is one such state that is developing a maintenance information system [3].

1.2 Previous Work in Phase I

In the first phase of the present study, a routine maintenance management information system (MIS) was developed for the Indiana Department of Highways (IDOH) [3]. The MIS was designed for application along existing organizational lines of the IDOH. Indiana is divided into six districts with five districts divided into six subdistricts and one district divided into seven subdistricts. Each of the thirty-seven subdistricts is responsible for routine maintenance of the state roads (including interstate) within its boundaries. The MIS was designed so that the field data recorded on crew day cards (Figure 1.1.1) can be used to produce necessary informational reports for maintenance managers to evaluate productivity values at the subdistrict level.

The MIS calculates unit productivity of each subdistrict and produces bar charts for crew size, material use, frequency of the activity that was performed, and other factors that are related to the maintenance activity being analyzed. Also, the mean productivity and standard deviation of the thirty-seven subdistricts is determined. The subdistricts are then placed in groups for comparison. The three groups used are low productivity, average productivity, and high productivity. The subdistricts are placed in these groups in the following manner. A subdistrict is considered to

FORM NO. MM 310 7/74

INDIANA STATE HIGHWAY COMMISSION

MAINTENANCE CREW DAY CARD

ACTIVITY NO.	ACTIVITY NAME	ROAD CLASS
207	SEALING CRACKS	CSH

MGMT UNIT	MANAGEMENT UNIT NAME	WORK CATEGORY
4200	MONTICELLO	LIMITED

DAYS PLANNED	DAYS REMAIN	MONTH	DATE
16	11	NOV	/ /74–75

ASSIGNED TO: | ROUTE / PROJECT | CO

LOCATION AND INSTRUCTIONS:

LABOR SUMMARY

CREW SIZE	TOTAL MANHOURS REGULAR	TOTAL MANHOURS OVERTIME
12		

EQUIPMENT

KIND	TYPE	COMM.	DESCRIPTION	USAGE	
02			PICKUP TRUCK		MI
02			PICKUP-CREW CAB		MI
03			DUMB TRUCK		MI
03			DUMP TRUCK		MI
11			TAR KETTLE		HR
58			TRACTOR		HR
58			TRACTOR		HR
68			AIR COMPRESSOR		HR

MATERIAL

CODE	DESCRIPTION	AMOUNT	UNIT
4431	BIT. MATERIAL		GAL
4521	SAND		TON

DAILY ACCOMPLISHMENT

SIGNATURE	AMOUNT	UNIT
		GAL MAT

Figure 1.1.1 Example of a Crew day Card

have a low productivity level if its unit productivity is less than one standard deviation from the mean productivity. Those subdistricts that are placed in the average productivity group are between plus and minus one standard deviation from the mean productivity. The high productivity subdistricts are those subdistricts that are greater than one standard deviation from the mean productivity.

By using the maintenance management information system to monitor the productivity of the subdistricts in executing the maintenance program, managers can spot problem areas where resources may not be used as efficiently as possible. On the other hand, bright spots may be discovered where subdistrict personnel have developed highly efficient methods of accomplishing their maintenance program. This can lead to corrective action being taken in the former case, and dissemination of methods and recognition of those responsible in the latter, resulting in an improvement in overall efficiency of the state's maintenance forces. A description of the development of the MIS is presented in the following section.

1.2.1 Description of the MIS

A computer program was developed to use the crew day

card data to produce relatively simple and straightforward reports showing various factors by which subdistrict performance may be assessed. On the basis of the crew day card records, the program determines the number of times a given activity was performed by each subdistrict, the total amount of work accomplished in the time period under study, the average accomplishment per crew day, the average crew size, the average number of manhours (both regular and overtime) per crew day, and the number of manhours per production unit. Also determined are the percent of the time a given material is used, the average quantity of material per production unit, when that material is used. The average cost per production unit is calculated, along with the labor cost and material cost per production unit. A summary of production amounts, labor and material use for each of the six districts and the state as a whole are also calculated. The subdistrict summary information can also be presented in bar chart form.

After determining these values for each subdistrict, the program takes the average cost figures for each subdistrict and calculates the average and standard deviation. Then, the average cost for each subdistrict is checked to see if it falls outside the range of the average plus or minus a given number of standard deviations. These deviate units are then listed.

Figure 1.2.1 is an example of the first page of output from the analysis of activity 201, shallow patching for the period from July 1982 through June 1983. This page presents all the input parameters necessary for the analysis. As it can be seen, the production unit of activity 201 is measured in terms of tons of bituminous mixture placed. There are six materials specified for this activity indicating that up to six of these materials may be used. These are determined by referring to the appropriate performance standard. The input data specify the code number and material description. For example, hot bituminous mixture is coded onto crew day cards as material 4441. The next column contains the material's unit price in dollars per unit of measure. The last column contains the maximum expected quantity of this material, a value used to detect typographical errors in entering the crew day card data. If a quantity of 30.0 tons of mix or greater were read, we would suspect that this is a coding error. That record would be rejected, and a data check message would be printed.

Next, the wage rates for regular and overtime hours are listed. These values are used to calculate the labor cost. Maximum expected values for crew size, manhours, and work accomplishment are then listed. These are used to check for typographical errors as explained before. The beginning and ending dates of the analysis period are

```
ROUTINE MAINTENANCE REPORT

INPUT PARAMETERB

ACTIVITY    201    Shallow Patching                    ACCOMPLISHMENT UNIT:    Ton of Mix

THE  6 MATERIALB SPECIFIED FOR THIS ACTIVITY ARE:

     CODE      DESCRIPTION                      UNIT COST($)  UNIT          MAX EXPECTED QUANTITY
     ----      -----------                      ------------  ----          ---------------------
     4441      Bituminous Mixture HOT                  25.50  Ton                          30.00
     4442      Bituminous Mixture COLD                 25.50  Ton                          30.00
     4443      Salvage Bituminous Mixture              0.     Ton                          30.00
     4431      Bituminous Material                     0.78   Gallon                     5000.00
     4251      Aggregate                               4.10   Ton                         500.00
     4252      Seal/Cover Aggregate                    3.00   Ton                         500.00

LABOR COST:
     Regular Hour     5.81
     Overtime Hour    5.81

VALUES FOR CHECKING DATA:
    Max Crew            30
    Max Hours          240
    Max Production    30.0

ANALYSIS PERIOD:     7-82    through    6-83

ANALYSIS FOR:
                OTHER STATE HIGHWAY

DEVIATIONS WILL BE DETECTED USING COST PRODUCTIVITY BEYOND + OR - 1.000 STANDARD DEVIATION(S)

PRINT CHART FOR:
                AVERAGE COST PER ACCOMPLISHMENT UNIT
                LABOR HOURS PER ACCOMPLISHMENT UNIT
                TOTAL PERIOD ACCOMPLISHMENT
                AVERAGE DAILY ACCOMPLISHMENT
                AVERAGE CREW SIZE
                QUANTITY OF MATERIAL 4431 PER ACCOMPLISHMENT UNIT

Beginning Record=        1
```

Figure 1.2.1. Example of Input Summary Page

listed. The short-test time period that can be considered is one month.

The next few lines indicate which program options have been selected. The program can analyze maintenance work for the Interstate system, for the Other State Highway system, or the Total highway system. The next line indicates that a subdistrict will be identified as being deviate in productivity based on average cost per unit of accomplishment plus or minus one standard deviation. The number of standard deviations to be used is entered by the analyst. Finally, the types of bar charts that will be printed are listed. There are six charts that may be printed for each highway class.

As mentioned earlier, there is a series of data check messages issued by the program. In addition to the previously described messages, the program also prints a message if it encounters a material that was not specified in the input information. An examination of the data records indicates that most of these messages result from coding errors. The number of rejected data records is very small. Considering the 1982-83 data for shallow patching, a total of 9 out of approximately 12070, records were rejected, or 0.07 percent.

Figure 1.2.2 shows a part of the labor summary page for the Other State Highway system. The first column

ROUTINE MAINTENANCE REPORT FOR ACTIVITY 201 Shallow Patching FROM 7-82 THROUGH 6-83
ACCOMPLISHMENT UNIT: Ton of Mix

OTHER STATE HIGHWAY LABOR INFORMATION

UNIT	CREW DAYS	ACCOMPLISHMENT TOTAL	ACCOMPLISHMENT AVERAGE	AVG CREW	TOT RH DAYS	RH/ACC	AVG RH	TOT RH	RH/TOT DAYS	TOT OT DAYS	OT/ACC	AVG OT	TOT OT	OT/TOT DAYS
1000	0	0.	0.	0.	0	0.	0.	0	0.	0	0.	0.	0	0.
1100	160	741.7	4.6	6.26	160	10.43	48.34	7735	1.000	3	1.48	11.00	33	0.019
1200	68	214.8	3.2	6.71	68	15.57	49.12	3340	1.000	1	2.00	4.00	4	0.015
1300	130	602.1	4.6	6.28	130	10.32	47.81	6215	1.000	0	0.	0.	0	0.

ROUTINE MAINTENANCE REPORT FOR ACTIVITY 201 Shallow Patching FROM 7-82 THROUGH 6-83
ACCOMPLISHMENT UNIT: Ton of Mix

OTHER STATE HIGHWAY MATERIAL INFORMATION

UNIT	CREW DAYS	MAT 4441			MAT 4442			MAT 4443			MAT 4431			MAT 4231			MAT 4232		
		FRAC	AVQNT	QNT/AC	FRAC	AVQNT	QNT/AC	FRAC	AVQNT	QNT/AC	FRAC	AVQNT	QNT/AC	FRAC	AVQNT	QNT/AC	FRAC	AVQNT	QNT/AC
1000	0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1100	160	0.80	4.75	1.00	0.13	3.67	1.00	0.	0.	0.	0.09	12.37	2.62	0.03	1.20	0.20	0.16	0.79	0.15
1200	68	0.54	4.00	1.00	0.44	1.17	1.00	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1300	130	0.62	4.77	1.00	0.22	2.45	1.00	0.	0.	0.	0.25	82.91	12.32	0.13	7.44	0.94	0.02	3.67	1.00

ROUTINE MAINTENANCE REPORT FOR ACTIVITY 201 Shallow Patching FROM 7-82 THROUGH 6-83
ACCOMPLISHMENT UNIT: Ton of Mix

OTHER STATE HIGHWAY COST INFORMATION (ALL COSTS ARE DOLLARS PER UNIT OF ACCOMPLISHMENT)

UNIT	CREW DAYS	TOTAL ACCOMP	TOT COST	LAB COST	MAT COST	COSTS BY MATERIAL 4441	4442	4443	4431	4231	4232
1000	0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1100	160	741.7	88.284	60.850	27.434	22.853	2.647	0.	1.821	0.033	0.080
1200	68	214.5	115.839	90.576	25.262	21.101	4.161	0.	0.	0.	0.
1300	130	602.1	83.792	59.972	23.820	16.352	3.007	0.	3.544	0.861	0.055

Figure 1.2.2. Excerpts from Labor, Material, and Cost Summaries

indicates the management unit, or subdistrict. Consider unit 1200, the Crawfordsville subdistrict. The "CREW DAYS" column repeated here. The next three columns give information about the use of material 4441, hot bituminous mixture, computed as shown below.

$$FRAC = \frac{TR}{TR_{4441}}$$

$$AVGQNT = \frac{TQ_{4441}}{TR_{4441}}$$

$$QNT/AC = \frac{TQ_{4441}}{TAC_{4441}}$$

Where,

FRAC = Fraction of the time material 4441 is used in activity,

TR = Total number of times activity is performed,

TR_{4441} = Total number of times material 4441 is used in activity,

AVQNT = Average quantity of material 4441 when it is used,

TQ_{4441} = Total quantity of material 4441 used,

QNT/AC = Average quantity of material per accomplishment unit,

TAC_{4441} = Total accomplishment for activity when material 4441 is used.

Thus, material 4441, hot bituminous mixture, was used 54% of the time that shallow patching was carried out, and the average quantity used was 4.8 tons per day. The average amount of material 4441 per unit of accomplishment was 1.00 ton. (This particular measure for this activity will always be 1.00, because the accomplishment is measured in tons of mix placed. Thus, tons of bituminous mix used divided by tons of accomplishment will equal 1.00). Similar calculations are made for each specified material.

The last section of Figure 1.2.2 presents a part of the average cost per subdistrict data. Again, the subdistrict number, the number of times the activity was performed, and the total production accomplishment are entered. The fourth column lists total cost per ton of shallow patching for materials and labor. In the case of Crawfordsville, unit 1200, the average cost for shallow patching was $115.84. The labor portion of this cost was $90.58, while the materials accounted for $25.26 per ton. The last columns break down material cost by material type.

Similar summaries are provided for each district and for the state as a whole.

Figure 1.2.3 indicates the results of the productivity deviation analysis. The average productivity

ROUTINE MAINTENANCE REPORT FOR ACTIVITY 201 Shallow Patching FROM 7-82 THROUGH 6-83

OTHER STATE HIGHWAY DEVIATION ANALYSIS

DEVIATION ANALYSIS BASED ON COST PRODUCTIVITY + OR - 1.000 STANDARD DEVIATION(S)

AVERAGE PRODUCTIVITY= 93.47 Dollars per Ton of Mix
STANDARD DEVIATION= 16.11
UPPER LIMIT= 109.58
LOWER LIMIT= 77.36

13 DEVIATE UNITS WERE DETECTED

UNIT	PRODUCTIVITY(COST/ACCOMP)
1200	115.84
1400	112.35
1500	120.48
2200	71.87
2300	77.18
3100	120.00
3400	134.98
3500	116.70
3600	71.56
4500	73.95
5200	58.63
5600	72.00
6100	116.84

Figure 1.2.3. Example of Productivity Deviation Analysis

of all 37 subdistricts was \$93.47 per ton, with a standard deviation of \$16.11 per ton. Using the average plus or minus one standard deviation, the lower limit is set at \$77.36 per ton, and the upper limit is \$109.58 per ton. All subdistricts whose average cost per ton for shallow patching falls outside this range are listed.

Figure 1.2.4 is a bar chart showing the average labor hours per accomplishment unit. The average and standard deviation are listed at the top. To the right, the values for hours, cost, and accomplishment are listed. Charts for the other factors are similar.

A complete description of the computer program including its use and outputs has been given in Appendix A of the interim report of the study [3].

1.3 Purpose of Phase II of the Study

The MIS framework developed in Phase I has provided a tool to identify differences in productivity among subdistricts. The purpose of Phase II was to identify which factors cause differences in productivity for particular activities and whether or not these factors should be incorporated into subdistricts' routine maintenance programs. This phase of the study dealt with the two highest cost pavement routine maintenance activities performed in Indiana: shallow patching

ROUTINE MAINTENANCE REPORT FOR ACTIVITY 201 Shallow Patching — FROM 7-82 THROUGH 6-83

OTHER STATE HIGHWAY

Average Labor Hours (Reg + Overtime) = 11.68 Hours per Ton of Mix
Standard Deviation = 2.75 Hours per Ton of Mix

Chart Shows Average Labor Hours (Reg + Overtime) per Ton of Mix

UNIT	HOURS/ ACCOMP	AVERAGE COST	ACCOMPLISHMENT TOTAL	ACCOMPLISHMENT AVERAGE
1100	10.47	88.28	741.7	4.6
1200	15.59	115.84	214.5	3.2
1300	10.32	83.79	602.1	4.6
1400	14.93	112.35	217.0	2.9
1500	15.91	120.48	467.1	3.1
1600	9.94	83.49	323.1	4.4
2100	11.61	94.07	909.5	4.0
2200	7.96	71.87	1310.9	5.9
2300	8.79	77.18	937.0	5.1
2400	9.45	79.91	883.5	3.8
2500	12.01	96.42	1040.4	3.7
2600	11.35	93.00	744.5	4.2
3100	16.26	120.00	266.1	2.9
3200	11.65	93.23	434.5	4.4
3300	12.16	97.06	547.1	4.5
3400	19.07	134.98	157.5	2.5
3500	15.60	116.70	300.0	2.9
3600	7.96	71.56	545.8	4.8
4100	10.87	88.10	433.5	4.0
4200	11.10	90.28	737.0	3.6
4300	11.68	93.84	1495.1	3.9
4400	11.91	94.65	594.7	3.6
4500	8.34	73.95	872.4	5.0
4600	9.42	79.47	914.0	4.5
4700	11.09	90.07	768.8	4.0
5100	9.95	83.41	577.5	3.5
5200	5.71	58.63	650.6	6.1
5300	13.25	102.42	300.4	3.1
5400	10.85	88.62	511.2	3.4
5500	11.00	93.35	293.7	3.6
5600	8.25	72.00	898.7	5.0
6100	15.72	116.84	203.9	2.8
6200	12.76	100.60	279.1	3.0
6300	11.68	93.20	424.4	3.9
6400	12.02	96.11	293.1	3.6
6500	12.54	99.89	457.7	3.9
6600	12.32	92.57	249.0	3.2

A — Average
1 — One Standard Deviation From Average
2 — Two Standard Deviations From Average
3 — Three Standard Deviations From Average

Figure 1.2.4. Example of Bar Chart for Labor Hours

(Activity 201) and crack sealing (Activity 207).

Identification of the factors that influence the productivity of shallow patching and crack sealing would aid in an effort to use the MIS framework for an overall increase in productivity levels of individual subdistricts.

1.4 Organization of the Report

The present report consists of 5 chapters and 4 appendices. In Chapter 2, a discussion of the results of a survey that was sent to each subdistrict is presented. The survey addresses reasons and areas of time delay during the performance of crack sealing and shallow patching.

Chapter 3 contains the procedure for conducting field observations. In order to determine an indication of site productivity, some agencies and private businesses use a method of work activities in place of work output. Use of work activities as a productivity measurement is determined through two techniques, work sampling or field observations and foreman delay surveys [8]. Both techniques measure time spent actually working and time expended on non-productive activities or delays. Field observations and subdistrict surveys were incorporated in identifying the factors that influence routine maintenance

productivity for the IDOH. Field observations of the work sites enable the measurements of productive and non-productive time of the field crews.

Chapter 4 contains a checklist for shallow patching (Activity 201) and crack sealing (Activity 207) that can be used by management and subdistrict superintendants as an aid in determining why particular subdistricts have higher or lower productivity levels than other subdistricts. Chapter 5 contains the summary and recommendations of the study. Appendix 1 is the statistical analysis of the data produced by the MIS [4] for fiscal year 1983. Statistical analysis of the data is helpful in identifying which factors cause the most variation in productivity.

CHAPTER 2

SUBDISTRICT SURVEY

2.1 Introduction

A questionnaire was developed and distributed to provide a better understanding of the productivity of crack sealing and shallow patching activities conducted by various subdistricts. A copy of the questionnaire developed is given in Appendix 4.

The questionnaire consisted of fourteen questions that were to be answered collectively by the superintendent, the general foreman and unit foremen of the subdistrict. The following is a list of the questions and the areas each dealt with.

1. Type of pavement each subdistrict was responsible for maintaining.
2. Type of roads each subdistrict was responsible for maintaining.
3. Shallow patching that was performed on each road type given in Question 2.
4. Shortest and longest delay times

experienced by the maintenance crews.

5. Reasons for the time delays experienced.
6. Type of patching mixture and sealant used and where they were purchased.
7. The greatest delay in shallow patching.
8. The greatest delay in crack sealing.
9. Presence of a unit foreman during crack sealing and shallow patching.
10. Scheduling of crack sealing.
11. Scheduling of shallow patching.
12. Quality assessment of field work.
13. Day-to-day differences in equipment; shallow patching and crack sealing.

    Use of a specific set of equipment.

There were two main reasons for the development of the questionnaire. One was to determine a background profile of the two activities. Questions 1 through 8 refer to this material. The second reason was to increase the data set by obtaining information not recorded on the crew day card computer data tape. Questions 9 through 14 refer to this objective.

Each subdistrict of the Indiana Department of Highways was sent a copy of the questionnaire. There are thirty-seven subdistricts in Indiana. Those subdistricts that did not respond within two months from the initial mailing were sent a second copy of the questionnaire with

a follow-up letter emphasizing the importance of the questionnaire to the study.

2.2 Percentage Return of Survey

Twenty-eight of the thirty-seven subdistricts completed and returned the questionnaire. The remaining nine subdistricts were contacted over the telephone and the answers to Questions 3, 4, and 9 were obtained from these nine subdistricts. Therefore, for Questions 3, 4 and 9 100 percent return was obtained and 76 percent return was obtained for the remaining questions.

2.3 Results of the Questionnaire Survey

The first use of the data was to compare subdistrict answers to the questions that required a written answer (not a number or percentage). These questions included reasons for time delays experienced in each activity (Question 5), whether a stockpiled mix or a hot plant mix was used for shallow patching (Question 6), the greatest cause of time delays for shallow patching and crack sealing (Questions 7 and 8), and differences in the type of equipment used for each activity, among subdistricts (Questions 12 through 14). The responses to these questions provided a better knowledge of the two activities being studied (crack sealing and shallow

patching). Also, differences among subdistricts concerning procedures and all reasons for time delays were noted so that these could be checked during the subsequent field observations. The responses to the questions showed many differences in equipment use, material use, and time delays among subdistricts.

The equipment used to compact the patch area differs among subdistricts. Some use a simple hand tamp while others use a mechanical compacter to compact the mix. Most every completed questionnaire returned had a different listing of equipment used to shallow patch and crack seal. Some subdistricts reported that they use the same grouping of equipment each time the activity was performed while others reported that they have no specific set of equipment they use when they shallow patch or crack seal.

The two main reasons for time delays in shallow patching and crack sealing operations given on the questionnaires were equipment failure and travel time to and from the work site. Approximately eighty percent of the returned questionnaires listed these two reasons for the greatest time delays experienced when shallow patching and crack sealing.

Two different types of mixes were reported as being used to shallow patch. The two types listed were stockpiled mix and hot plant mix. The names of the plants where the mix was purchased were also given on the questionnaire. No differences in the type of sealant used to crack seal were listed on any of the returned forms. Generally, it was found through the survey that a variety of shallow patching and crack sealing procedures are used in the the field.

The responses to the questions that required a number or a percentage were used to compare different groupings of subdistricts. The percentage of road types each subdistrict is responsible for maintaining (Questions 1 and 2), the percentage of work done on each road type (Question 3), the shortest and longest time delays experienced for each activity (Question 4), and the percentage of time a unit foreman accompanies the maintenance crews to the work sites (Question 9) all required a percentage or frequency response. Two different comparisons were made of Questions 3, 4 and 9. The two comparison were:

1) High cost subdistricts versus low cost subdistricts.

2) Northern subdistricts versus southern subdistricts.

The high cost and low cost groups were identified by analyzing the MIS data as discussed in Appendix 1 for each routine maintenance activity under investigation. The northern and southern groups were considered to determine if differences in climatic conditions found in the northern and southern portions of the state affected the maintenance work performed. Figure 2.3.1 shows the northern and southern subdistricts.

2.4 Comparison of High Cost and Low Cost Subdistricts

A comparison of Questions 3, 4 and 9 were made for both activities (shallow patching and crack sealing) between high cost and low cost subdistrict groupings. The mean response of each group to each question is given in Table 2.4.1. The difference between the group means for Questions 3, 4, and 9 were found to be small. Statistical analyses were performed to determine whether there was a statistical difference among groups. All comparisons were found to be insignificant at an α-level of 0.05. However, the percentage of time shallow patching was performed on interstate (Question 3a) was found to be statistically different for high cost and low cost groups at an α-level of 0.10. Table 2.4.2 contains the ANOVA`s run on the data. It was not necessary to perform a statistical analysis on each question due to the fact that the

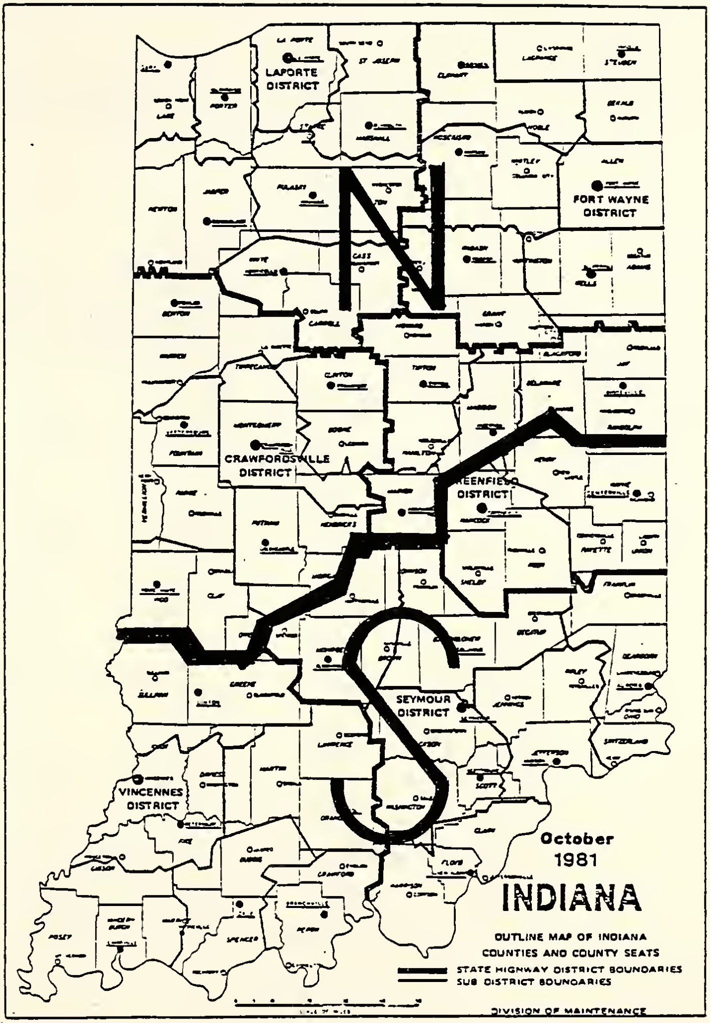


Figure 2.3.1 Division of the State into Northern and Southern Subdistricts.

Table 2.4.1 Mean Response to Selected Questions on the Survey for High and Low Cost Subdistrict Groupings.

Question Number	Activity Number	Mean Response of Group High Cost	Low Cost
3a	201	18.9	5.2*
3b	201	21.3	27.2
3c	201	59.0	67.7
3a	207	6.6	6.9
3b	207	19.3	27.0
3c	207	74.1	66.1
4 minimum	201	0.40	.43
4 maximum	201	1.14	1.08
4 minimum	207	0.36	0.39
4 maximum	207	1.09	1.18
9	201	39.7	28.7
9	207	51.9	62.6

Table 2.4.2 Comparison of High and Low Cost Subdistrict Groupings.

Question	Activity	MS Group	MSE	F*
3a	201	683.738	177.297	3.86
3a	207	0.201	56.826	0.00
9	201	335.502	608.746	0.55
9	207	320.667	963.210	0.33

difference between group means was very small. High cost subdistricts perform shallow patching an average percentage of 18.9 on interstate, where low cost subdistricts perform shallow patching an average percentage of 5.2 on interstate. Therefore, the field observations should focus on the differences in patching techniques used on interstate roads.

Most of the data obtained through the questionnaire can not be validated. The questions were answered by unit foremen and subdistrict superintendents and the answers may have been biased. The data obtained may overestimate or underestimate the actual answers to the questions. Therefore, the results of the analysis of the survey data are in no way conclusive. However, the data can be used to locate general areas where differences among subdistricts and subdistrict groupings may exist.

2.5 Comparison of Northern and Southern Subdistricts

The 37 subdistricts were divided into two groups, northern and southern subdistricts (see Figure 2.3.1). This was done because of the climatic differences that exist between the northern and southern portions of the state.

From the results of the survey data, presented in Table 2.5.1, it can be seen that the northern and

Table 2.5.1 Mean Response to Selected Questions on the Survey for Northern and Southern Subdistrict Grouping.

Question Number	Activity Number	Mean Response of Group Northern Subdistricts	Southern Subdistricts
3a		10.9	8.4
3b	NA*	22.0	21.0
3c		66.6	70.9
4 min.	NA	0.37	0.42
4 max.		1.14	1.11
9	201	27.4	28.4
9	207	50.7	45.2

* NA = not applicable.

southern groups had similar mean responses to all of the questions tested (Questions 3, 4 and 9). However, Questions 13 and 14 listed differences in the type of equipment used in northern and southern subdistricts. Differences in equipment used to apply the bituminous sealer were recorded. The northern subdistricts listed using pour buckets more often than the northern subdistricts. The subsequent field observations focused on this difference.

2.6 Conclusions

The survey developed was useful in that it provided basic background information on shallow patching and crack sealing. It was also helpful in pointing out differences in equipment use among subdistricts.

The survey provided information on the time delays for each maintenance activity. Different causes of non-productive time were listed and can therefore checked during the field inspections.

Overall, the survey allowed information to be gathered on shallow patching and crack sealing that was not contained on the data tapes.

CHAPTER 3

FIELD OBSERVATIONS OF ROUTINE MAINTENANCE ACTIVITIES

3.1 Definition of Field Observations of Routine Maintenance Activities

To be able to analyze fully productivity of routine maintenance activities, it was necessary to perform site observations or field observations of the routine maintenance crews. Field observations provided for the collection of qualitative as well as quantitative data. Correlation of crew day card information with the field data was used to identify the factors that influence routine maintenance productivity.

Sites for field observations were nonrandomly selected. The field observations for this project had to be selected at specific locations throughout the state in order to identify effectively the factors that influence routine maintenance productivity. Location of the sites were based on the following factors:

1. The Management Information System (MIS) system places each subdistrict into one of three groups: low

productivity, average productivity, or high productivity. A field observation of at least one subdistrict from each group was conducted.

2. Sites were selected from subdistricts located at different geographical locations in the state.

3. Classification of road type that the work was to be performed was considered. A field observation was made of each routine maintenance activity performed on each road type. One field observation was made on a two lane road, one on a four-lane road, and one on interstate. These observations were not all done for each subdistrict yet each road type was included in at least one of the observations performed.

4. Observations were made to include activities on rigid pavements, flexible pavements, and overlayed pavements.

The method utilized for field observations consisted of one observer accompanying a routine maintenance crew to the job site, observing and recording the prework, actual work, and post work characteristics of crew, equipment, and road. Written field reports and slides were used to record the observations for routine maintenance activity numbers 201 and 207 (shallow patching and crack sealing, respectively).

3.2 <u>Categories of Recorded Field Inspections</u>

In Figure 3.2.1 is shown a copy of the written form used to record the field observations. In addition, slides were taken to verify comments made by the observer on the written form. Categories of recorded information can be divided into the following seven areas:

1. Statistical information of the field observation. General information of the field observation is recorded here including location, date, subdistrict, weather and temperature, activity number and type, the duration of the observation, and estimation of the work completed during the observation.

2. Crew Information. Information of the crew doing the task must be recorded. Crew size, crew foreman or lead worker, and the role or task that each crew member was assigned were recorded. Any changes in the information, such as the role of each crew member throughout the day, was also noted on the field form.

3. Equipment Information. For this category, a listing of the equipment that was present at the job site was recorded as well as whether or not the equipment was actually used during the work process.

4. Material Information. Material information consists of the type of material used at the job site, the

OBSERVER ____ PAGE ____

LOCATION ____ DATE ____

SUBDISTRICT ____

WEATHER ____

ACTIVITY/NUMBER ____

DURATION OF OBSERVATION ____

ESTIMATION OF ACCOMPLISHMENT ____

CREW SIZE ____ FOREMAN ____

CREW MEMBERS ROLES ____

EQUIPMENT USED MATERIALS USED

PRE-WORK ROAD CONDITIONS

WORK HABITS

CREW MEMBER COMMENTS

Figure 3.2.1 Form Used to Record Field Observations.

amount of material at the start of the operation, and the temperature of the material.

5. Pre-work Road Conditions. Road conditions before actual repair work began were recorded. First, the type of pavement and type of roadway were recorded. The type of pavement could be rigid, flexible and asphalt overlayed pavements. The type of roadway could be interstate, other state roads-multilane, or other state roads-two lane. Second, the surface condition of the pavement was recorded. The observer recorded distresses present and then made a judgmental evaluation of pavement condition. The observer also checked for the presence of previous road work done to the pavement.

6. Work Habits. Work habits reported included the arrangement of equipment and personnel in the order that they appeared when performing the maintenance activity. Any preparatory work was recorded including any cleaning of the road surface or removal of remnant patching or sealant.

7. Crew members' comments on the activity performed. The recording of crew members' comments on the job they were performing aided in determining productivity differences among subdistricts. Crew members' attitudes and opinions about the job they

were performing could be formulated through their comments. An insight into a crew's effectiveness could be obtained through a conversation where answers to specific questions are weighed with the actual work habits observed. For instance, a set of specific questions were asked of each crew observed and the answers recorded on the field form in Figure 3.2.1. The observer did not always get an answer to every question and therefore there may be missing data on the field forms. The questions asked of each crew were listed for the questioner on a separate sheet, but the answers were recorded on the field form, Figure 3.2.1. The questions were:

a. Do you work with the same crew members each time you shallow patch (crack seal)?

b. Do you perform the same job at each work site?

c. Does the type of mix used in shallow patching affect your performance and productivity?

d. Which road type is easiest to shallow patch (crack seal) for your crew?

e. What causes the most delay of work in shallow patching (crack sealing)? Do you think performance today is below average, average, or above your average daily accomplishment?

f. Do you think your work today is worthwhile?

g. Do you have any control over the quality of the material you use for a specific activity?

h. Pertaining to shallow patching, what percentage of the time are you sent from one plant to another plant when picking up road mix?

The questions above were not the only questions asked by the observer in most observations, but the nine given above were always asked during the field observation.

3.3 Routine Maintenance Activities Studied

Two different routine maintenance activities were studied in this project, shallow patching (Activity 201) and crack sealing (Activity 207) [4].

3.3.1 Shallow Patching (Activity 201)

Shallow patching is minor patching of small area deformations of both rigid and flexible pavements. The material used in this activity can be either a "hot plant" bituminous mixture or a "cold" bituminous mixture. These two terms, "hot plant" mix and "cold" mix, lead to confusion of properties of these mixes in the field.

By definition, "hot plant" mix consists of a combination of aggregates uniformly mixed and coated with asphalt cement. To dry the aggregates and obtain sufficient fluidity of the asphalt cement for proper mixing and workability, materials must be heated prior to mixing giving the origin to the name "hot-mix" [11]. By definition, "asphalt cold mix is a mixture of unheated mineral aggregate and emulsified or cutback asphalt" [12].

Some subdistricts in Indiana stockpile an adequate amount of cold mix to last for one season of shallow patching. In most instances, the cold mix is placed in a porta-patcher (mechanical device to heat mixes) and heated to approximately 150° to 200° F. Some superintendents consider a heated cold mix to be the equivalent of a hot mix that is obtained from a plant. A heated cold mix is not a hot plant mix, it is a hot emulsified mix.

There is an extreme difference between an asphalt cement and an emulsified asphalt. An asphalt cement is a particular grade and type of asphalt that is produced from the fractional distillation of crude petroleum where an emulsified asphalt is a mixture of asphalt and water in the presence of an emulsifing agent. These two types of asphalt products have different physical and chemical properties. These differences diminish with time and depend greatly on the formula used in preparing the emulsified asphalt, yet there are still differences

between the two types of mixes that are not erased by the heating of the emulsified asphalt.

Shallow patching is performed on surface failures, "pot holes", caused by localized disintegration of the pavement surface. Causes for surface failures are usually one or a combination of the following [13]:

1. Too little asphalt in the pavement.
2. Too thin an asphalt surface.
3. Failure of the base.
4. Poor drainage.

The Indiana Department of Highways (IDOH) has mandated a set work procedure (see Figure 3.3.1) that is comparable to the work procedure given by the Asphalt Institute [13] with the exception that the Asphalt Institute recommends the use of infra-red heaters to dry the damaged section, soften the surrounding asphalt, and dry the compacted patch.

3.3.1.1 Subdistricts Included

Field observations of shallow patching work were conducted during 1983 at five Indiana subdistricts, Crawfordsville (2), Fowler (3), Indianapolis (13),

INDIANA DEPARTMENT OF HIGHWAYS
DIVISION OF MAINTENANCE

PERFORMANCE STANDARD

ACTIVITY	Shallow Patching	CODE	201

DESCRIPTION AND PURPOSE Minor patching small areas of bituminous roadway or paved shoulder surface with hot or cold bituminous mixtures and hand tools to correct potholes, edge failures, and other potential surface hazards. This activity also includes temporary patching of bituminous and concrete surfaces and the use of hot liquid bituminous material and aggregate for patching bituminous surfaces or crack and joint spalling of concrete surfaces.

AUTHORIZED BY	Subdistrict	WORK CONTROL CATEGORY	Unlimited

SCHEDULING Repair surface failures exceeding 2" in depth and 1' in diameter as soon as possible after they are reported. Other surface failures which do not present a hazard to traffic shall be scheduled as routine maintenance prior to the beginning of inclement weather. (November 1).

CREW SIZE 5-8 MEN

WORK ASSIGNMENT	QTY.
Flagman	2
Truck Driver/Laborer	2
Laborer	1-4

EQUIPMENT	QTY.
Dump Truck	1
Pickup-Crew Cab	1
Premix Storage Trailer	1
Compactor (hand or mechanical)	1

MATERIALS

Bituminous Mixture (applied hot or cold)
Bituminous Material
Aggregate
Cover Aggregate

AVERAGE DAILY PRODUCTION 1-6 Tons Bituminous Mixture or Aggregate

WORK METHOD

Refer to the following page for appropriate work method.

+ Bituminous Mix
+ Bituminous Material and Aggregates

NOTE: Temporary patches should be replaced with permanent patches using the above work method when weather permits.

APPROVED BY:

K M Mellinger
CHIEF, DIVISION OF MAINTENANCE

D. W. Lucas
DEPUTY DIRECTOR, HIGHWAY OPERATIONS

EFFECTIVE DATE JULY 1, 1981

FORM NO. MM-309(M)

Figure 3.3.1 Performance Standard for Activity 201.

Bloomington (27) and Fort Wayne (10). Figure 3.3.2 presents the location of these subdistricts. A written field report and slides were used to record each field observation. The subdistricts were compared for differences and similarities of actual work practices of shallow patching.

3.3.1.2 Differences Among Subdistricts

From the field observations conducted, the following six main areas of differences were found to exist among the subdistricts considered.

1. Field Supervision

Some subdistrict crews are accompanied by a unit foreman while other subdistrict crews are not. Productivity of the crew on the job site was greater and the quality of work was better when the unit foreman was present at the job site.

The level of training of the crew members differed among subdistricts. There were crew members who believed that part of the patching procedure was a waste of time and should be excluded from the set procedure for shallow patching. Some crew members believed that pre-patch preparation of the patching area was not necessary. Others believed that traffic

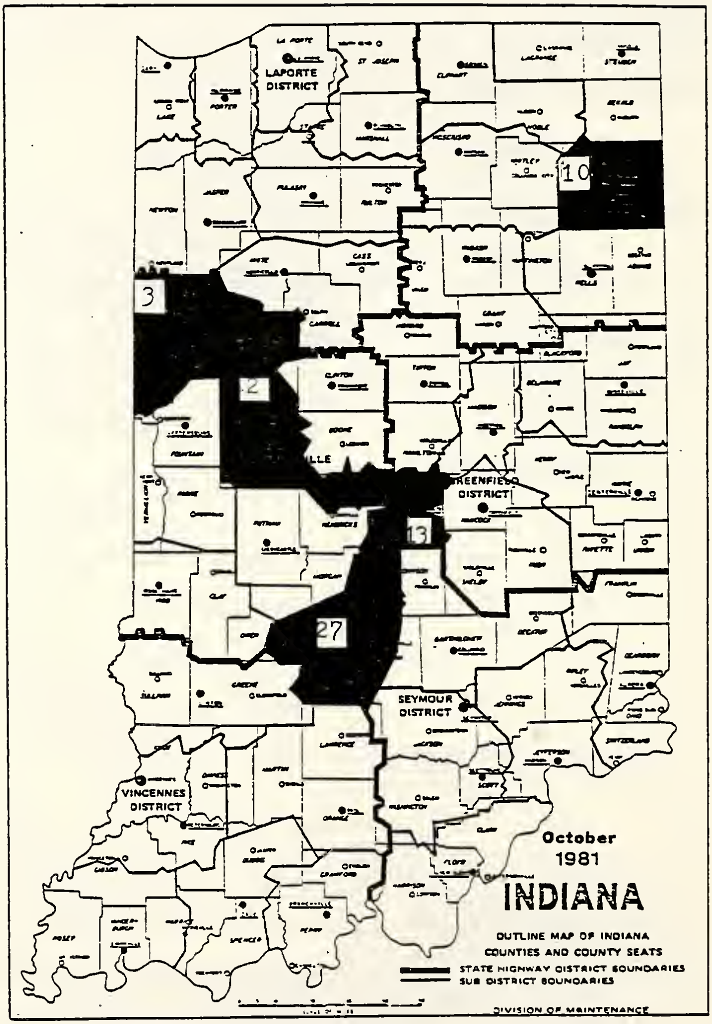


Figure 3.3.2 Subdistricts Included in the Field Observations of Activity 201.

would compact the patch area and they would therefore leave the patch area poorly compacted.

2. Crew Size

The number of crew members used to shallow patch ranged from four to seven. From the standpoint of safety, four crew members was too few while with a crew size of seven, there were usually one or two crew members who were underutilized. Five or six man crews seemed to be the ideal size to keep all workers productive as well as to ensure safety. The most productive work assignment observed was one driver (dump truck carrying mix or pulling hot bin), 3 laborers (1 shoveling mix, 1 raking mix, and 1 compacting mix), and one to two flagmen (depending on type of road and terrain of area). Also, productivity of crews whose members switched duties throughout the day appeared higher than crews whose members` duties remained the same for the work session.

3. Equipment

The equipment used in shallow patching varied slightly from subdistrict to subdistrict. Main differences in equipment used dealt with compaction of the bituminous mix. Three methods of compaction

were observed in the field. One method of compaction was running a vehicle`s tires over the uncompacted mix. A second method was the use of a hand tamp to compact the bituminous mix (see Figure 3.3.3). Within this method there were a variety of compaction levels. They range from very little force applied with the hand tamp to adequate force applied with the hand tamp. The last method of compaction was by the use of a "wacker." A "wacker" is a hand controlled vibratory plate compactor that compacts the patch by repeated impact loadings (see Figure 3.3.4). From the three methods listed above; 1) vehicle-tire compaction, 2) hand tamp compaction and 3) vibratory compaction), it was observed that the quality of the patch increased respectively. Quality here refers to visual observations of the patch such as whether the whole patch area had been compacted, whether the surface of the patch area was level with the existing road, and whether the patch material was easily loosened and dispersed by traffic.

4. Type Mix Used for Patching

The type of bituminous mix used for shallow patching varies from subdistrict to subdistrict. Various subdistricts use stockpiled bituminous mix that is heated in a porta-patcher prior to use. (see

Figure 3.3.3 Patch Compaction by the Use of a Hand Tamp.

Figure 3.3.4 Patch Compaction by the Use of a Vibratory Compactor.

Figure 3.3.5 and Figure 3.3.6 for an example of a porta-patcher and a stockpiled mix respectively). The stockpiled mix is stored at the unit garages located within the subdistricts. The other subdistricts use hot plant mix that is picked up daily from a batch plant. The difference in shallow patching productivity due to materials result from different down times occurred in picking up the mix. There is an average of 1 - 1 1/4 hours used to retrieve bituminous mix when using hot plant mix. Usually, there are two men sent to pick up the mix while the remaining crew members are paid for no (non-productive) work.

Stockpiling of bituminous mix decreases the down time of the crew because the mix is already stored at the garage. There is a small amount of down time caused from loading the mix in the trucks at the beginning of each shallow patching work day.

There were also differences in the mix characteristics from day to day that affected the mix workability which in turn affects productivity.

5. <u>Effect of Road Type on Productivity</u>

The type of road that is being maintained affects productivity of shallow patching.

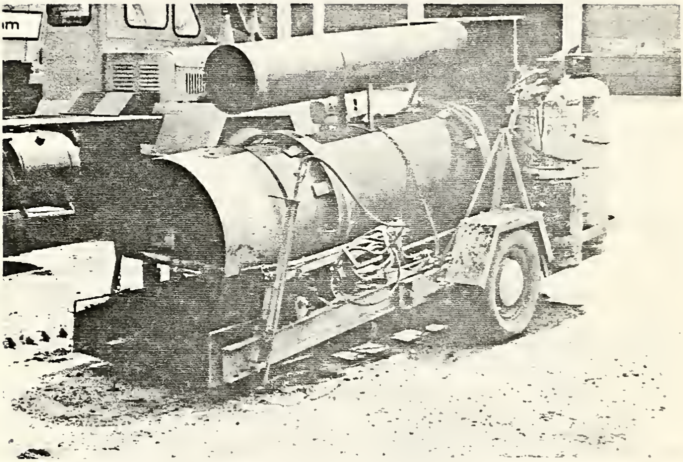


Figure 3.3.5 Example of s Porta-Patcher.

Figure 3.3.6 Example of a Stockpiled Mix.

Differences occur between two-lane roads versus multi-lane roads (in shallow patching productivity) due mainly to traffic density and crew safety. Typically productivity on four-lane roads is less than on two-lane roads when the patching areas of each road type are similar, because of the higher traffic volumes and vehicle speeds and the safety precautions necessary to be taken by maintenance crews under these conditions.

6. Patch Size

Patch size can affect shallow patching productivity. Most shallow patching performed is a continuously moving process filling in potholes as the crews move down the road. However, there are instances when large area patches are repaired using a large amount of bituminous mix within a small road distance. This is not a continuous patching operation and will have a large productivity level (if all other factors remain constant) due to the large amount of material used in a small time period. Unfortunately, the production unit used for shallow patching, dollar cost/ton of mix applied, will not distinguish among the two types of patching.

3.3.1.3 Discussions

The areas listed above can significantly affect the productivity of shallow patching by affecting the labor costs of performing the task. As bituminous mix costs are generally fixed, any differing characteristic in the mix, whether it is between hot mix and stockpiled mix or differing characteristics of one mix type from day to day, would increase or decrease labor costs.

On the basis of the field investigations performed, the following suggestions can be made to increase productivity as well as the quality of shallow patching performed in Indiana.

1. A crew size of five or six appeared to be the ideal size for shallow patching.

2. Compaction of the applied mix is essential to the longevity of the patch. Mechanical patching produces the highest quality patch and can be done without significantly decreasing productivity. A device as shown in Figure 3.3.7 would produce adequate compaction of the patching material for small patches while the device shown in Figure 3.3.8 should be used for large area patches [14].

3. Down time from material preparation or pick up needs to be reduced. The use of stockpiled mixes would

Figure 3.3.7 Example of a Mechanical Compactor Used for Small Area Patches.

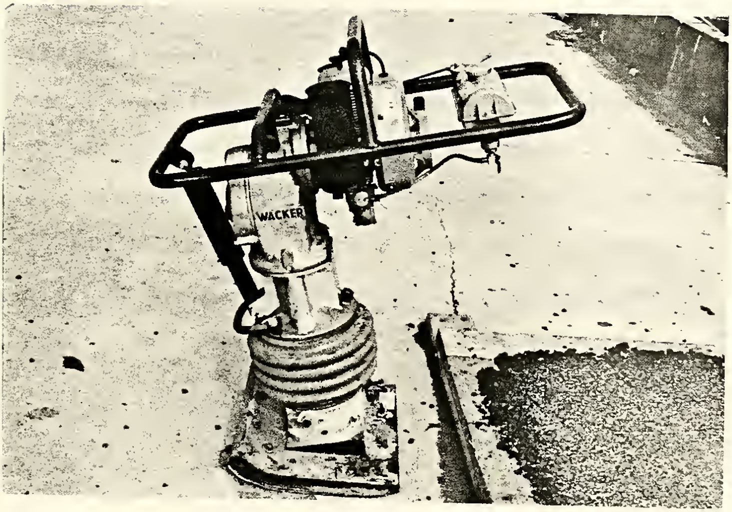


Figure 3.3.8 Example of a Mechanical Compactor Used for Large Area Patches.

eliminate the down time experienced with hot plant mix use. However, there is still down time experienced when using stockpiled mix due to heating the mix for use. Furthermore, the use of stockpiled mix may indicate a higher productivity, but the quality of patching may not be as high as that can be expected with hot plant mix.

4. Another approach to reduce down time would be to pay one crew member overtime for one day (1-2 hours) to retrieve the hot plant mix before the work day begins. Then actual patching could begin at the beginning of the day. The cost difference would be paying 1 man 1-2 hours of overtime for actually working versus paying 4-5 crew members regular hourly wage for 1-2 hours of no work. Each crew member could be assigned to one day each week to pick up hot mix at the plant. This same approach can be applied to heat stockpiled mix used in shallow patching.

5. Pre-patch work is necessary to extend the life of the patch according to the Asphalt Institute Manual Series No. 16 [13]. From the field obsevations conducted, it appeared that some hole preparation should be conducted. Removal of loose material, dirt and vegetation should be done and the potholes should be relatively free of water.

6. Some other suggestions for use of personnel during down times are the following: 1) While the bituminous mix is being picked up, other crew members travel down the patching areas circling patch areas with paint so that these areas are not missed once actual patching begins. This usually refers to a road that is in good shape that has a few isolated areas that need patching. 2) Pre-patch preparation of large area patches could be done during down time. The patch area could be primed for the bituminous mix so that patching begins as soon as the mix arrives at the job site.

3.3.2 Crack Sealing (Activity 207)

Crack sealing is a process of cleaning and sealing of open cracks and joints in bituminous and concrete pavements as well as paved shoulders to prevent entry of moisture and debris in the cracks which could lead to surface and base failure of the pavement.

Ideally, the cracks are cleaned of debris (by use of an air compressor or by sweeping) and then a bituminous material is applied into and around the crack. A squeegee is used to assist in forcing the filler into the crack and a layer of sand is spread over the filled crack to reduce pickup by traffic. The type and grade of bituminous

material used varies from job site to job site.

The actual equipment used to perform each step in the above process varies from subdistrict to subdistrict depending on geographical and climatic conditions, availability of equipment, and past experience of crack sealing within the subdistrict.

Crew size also varies from subdistrict to subdistrict. Figure 3.4.1 is a copy of the performance standard that the subdistrict crews are to follow for crack sealing [4]. Under the category of equipment, two items are not listed that are used in the field. These are 1) a distributor and 2) pour buckets.

There are various types of cracks and causes of cracks found in pavements. The Asphalt Institute Manual Series No. 16 [13] gives detailed description of various crack types.

INDIANA DEPARTMENT OF HIGHWAYS
DIVISION OF MAINTENANCE

PERFORMANCE STANDARD

ACTIVITY	Sealing Cracks	CODE	207 PM

DESCRIPTION AND PURPOSE Cleaning and sealing open cracks and joints in bituminous and concrete roadways and paved shoulder surfaces to prevent the entry of moisture and debris which leads to surface and base failure. This activity also includes sealing short sections or isolated areas of alligatored, raveled, or spalled bituminous surfaces to prevent entry of moisture and further deterioration of the surface.

AUTHORIZED BY	Subdistrict	WORK CONTROL CATEGORY	Limited

SCHEDULING Perform on areas where there is loss of seal or cracking or the joint filler is broken, brittle or missing and allowing entry of water and foreign material. This work should be scheduled in the cooler months when contraction has opened the crack or joint. Do not cover painted lines or messages without prior approval of District Traffic.

CREW SIZE 11 MEN

WORK ASSIGNMENT	QTY.
Supervisor	1
Flagman	2
Pickup or Tractor Operator	2
Air Compressor Operator	1
Tar Kettle Spray Operator	1
Laborer	2
Truck Driver/Laborer	2

EQUIPMENT	QTY.
Pickup or Tractor/Air Compressor	1
Pickup or Tractor/Tar Kettle	1
Dump Truck	2
Pickup Truck	1
Pickup/Crew Cab	1

MATERIALS

Bituminous Material
Cover Aggregate

AVERAGE DAILY PRODUCTION 2 - 4 Lane Miles

WORK METHOD

1. Place signs and other safety devices.
*2. Clean crack as required.
3. Apply bituminous material to cracks.
4. Squeegee material to force into cracks and surface voids.
5. Remove any surplus material.
6. Dust the area lightly with cover aggregate.
7. Remove signs and safety devices.

* When routing of the joint or crack on concrete surfaces is required before sealing, see Activity 219, Other Roadway and Shoulder Maintenance.

APPROVED BY:

K M Mellinger
CHIEF, DIVISION OF MAINTENANCE

D. W. Lucas
DEPUTY DIRECTOR HIGHWAY OPERATIONS

EFFECTIVE DATE JULY 1, 1982

FORM NO. MM-309(M)

Figure 3.4.1 Performance Standard for Activity 207.

In general, crack sealing is performed for the following reasons:

1. To prevent surface water seepage into the base and subbase.

2. Protection of the joint filler.

3. To prevent foreign matter collecting in joints and cracks.

Failure to crack seal may result in the follow pavement distresses:

1. Pumping in rigid pavements

2. Weakening of the base and subgrade

3. Increased damage from frost action

4. Point stress and pressure ridge formation

5. Deterioration of joint fillers

6. Oxidation of dowels and rebars

There have been questions as to whether or not crack sealing actually adds to the pavement life. A recent study performed at Purdue University indicated that the level of expenditure in post-winter shallow patching is inversely proportional to the level of expenditure in

pre-winter crack sealing [15].

Crack sealing is not performed all twelve months of the year, as shown in Figure 3.4.2. Crack sealing is usually performed in the cooler months, September through early December for two reasons.

1. The cracks are wider in the cooler months due to contraction of the pavements.

2. The bituminous material applied to the cracks is heated and is in a liquid to semi liquid state. Once applied, the cooler temperatures help to solidify the material, thereby reducing the amount of material that flows out of the cracks and also reduces the amount of material that is picked up by traffic traveling on the road after it has been reopened.

3.3.2.1 Subdistricts Included

Field observations were conducted during 1983 and 1984 at five Indiana Subdistricts, Fowler (3), Monticello (20), Crawfordsville (2), Fort Wayne (10) and Bluffton (11). The location of these subdistricts is shown in Figure 3.4.3. There was also a field observation of Bloomington (27) conducted earlier [3]. A written field report and slides were used to record each field

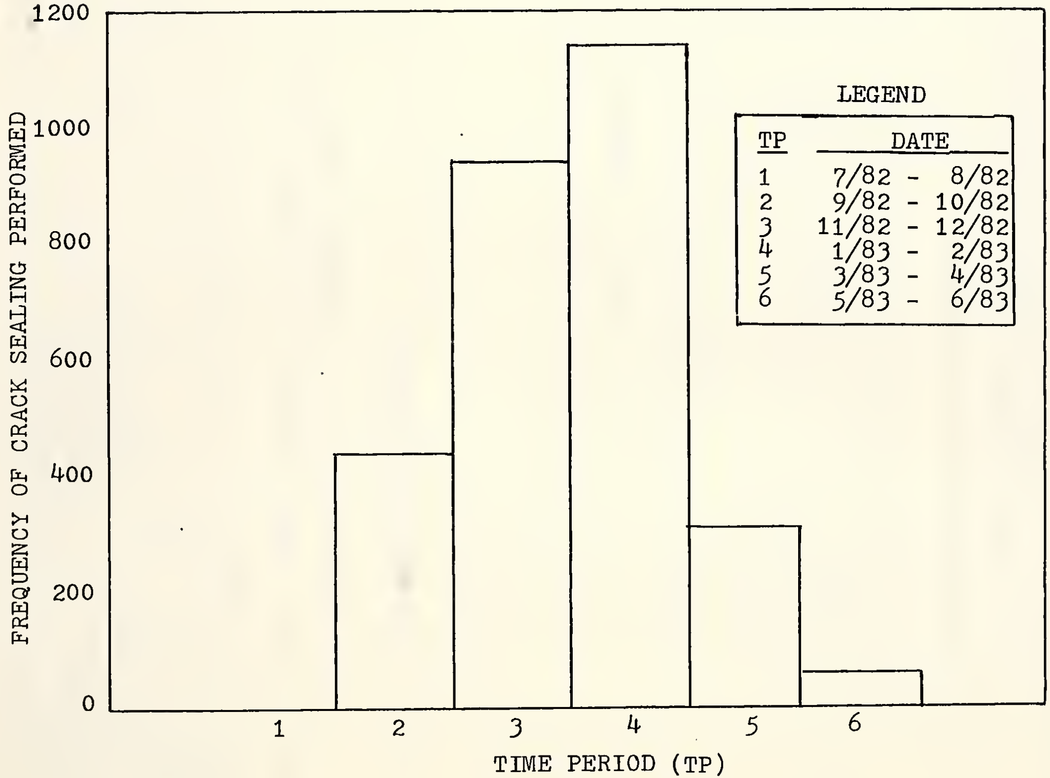


Figure 3.4.2 Frequency of Crack Sealing Performed During the 1983 Fiscal Year.

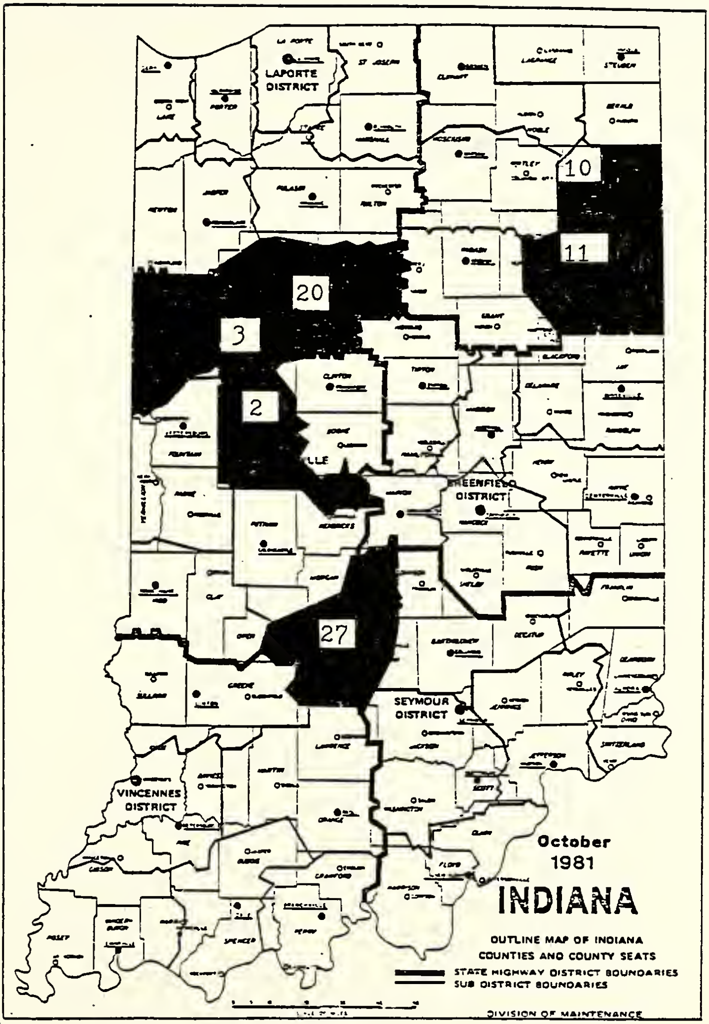


Figure 3.4.3 Subdistricts Included in the Field Observations of Activity 207.

observation. The subdistricts were compared for differences and similarities of actual work practices of crack sealing.

3.3.2.2 Differences Among Subdistricts

There were four main areas of noticeable differences among subdistricts performing the task of crack sealing.

1. Crew Size

   The number of crew members of a particular subdistrict, used to crack seal, ranged from 9 to 11. The performance standard set by the IDOH calls for a crew size of 11 [4]. From the field observations, an 11 man crew size is too large. Usually, 1 or 2 crew members in a large crew would do little or no work. The crew size that seemed to be optimal consisted of eight or nine members. This would allow for three drivers, one pulling an air compressor, one pulling a heating unit, and one driver for the sand truck. One man would operate the air compressor nozzle and one man would operate the heating unit nozzle. This crew size allows one flagman behind the operation, and 2-3 general laborers using squeeques. This crew size seemed to work most efficiently while making use of all laborers.

2. Equipment

Different equipment is used to crack seal from subdistrict to subdistrict. Some subdistricts use an air compressor to blow the cracks clean before applying the seal material (see Figure 3.4.4), others do not. The operator of the air compressor increases the crew size by one, increases the cost of crack sealing without an increase in the number of lane miles sealed, and therefore decreases productivity of the crew when productivity is defined as cost per lane mile sealed. However, subdistricts that do not use an air compressor to blow the cracks clean run the risk of point stress developing in rigid pavements due to incompressible material in the crack and pressure ridges forming in bituminous pavements and overlays [16].

Point stresses due to imcompressible material in the crack or joint come from the expansion character of pavements with an increase in temperature. Stress developed in the pavements is given by:

$$\sigma = E(\alpha \Delta t - \delta) \qquad (3.1)$$

where,

σ = stress

Figure 3.4.4 Example of Cleaning Road Cracks.

E = modulus of elasticity

α = coefficient of thermal change

Δt = change in temperature

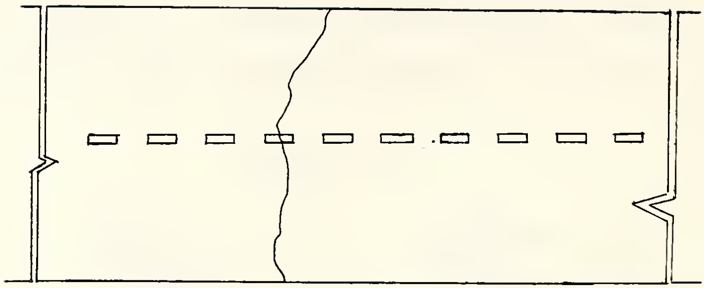
δ = coefficient of expansion

When imcompressible material is present in the cracks, $\delta = 0$ and the equation takes the form:

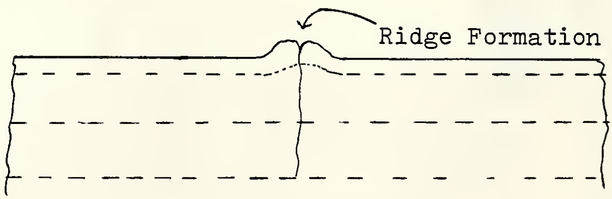
$$\sigma = E\ (\alpha \Delta t) \tag{3.2}$$

This stress development is the same for both rigid and flexible pavements. However, due to the difference in physical and chemical characteristics of the pavement types, the resulting deformations are different. With rigid pavements, resulting deformations are blow ups and punch outs while with flexible pavements deformations are in the form of pressure ridges. Pressure ridges are a mounding or heaving of pavements about the crack (see Figure 3.4.5) [17].

There were three different methods of applying the bituminous material to the cracks observed during the field investigations. These methods were the use of a distributor with a hand held nozzle attachment (see Figure 3.4.6), use of a heating unit with a hand held nozzle (see Figure 3.4.7), and the use of pour buckets (see Figure 3.4.8). There was very little



Plan View of Cracking



Side View of Cracking

Figure 3.4.5 Pressure Ridge Formation About a Crack.

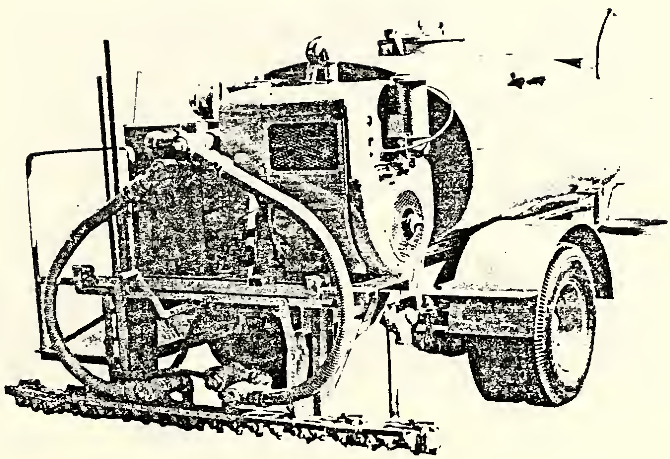


Figure 3.4.6 Example of a Distributor.

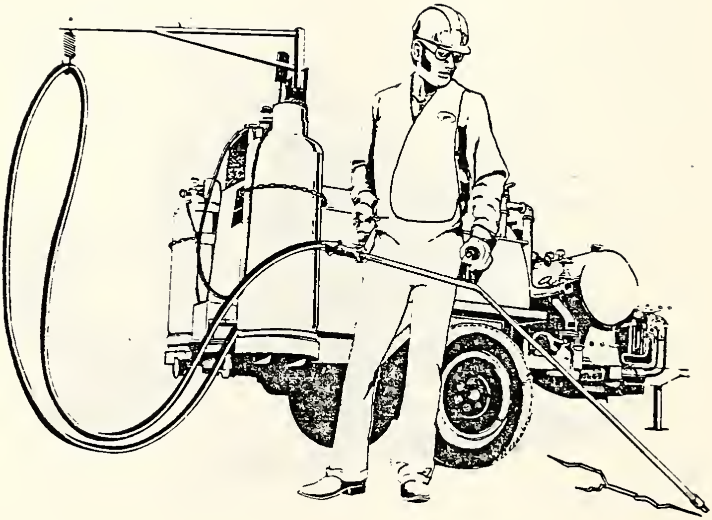


Figure 3.4.7 Example of a Heating Unit.

Figure 3.4.8 Example of a Pour Bucket.

difference between the use of distributors and the use of heating units. The hand nozzle attachments for both were the same and the number of crew members needed to use these two types of equipment were the same. There may be one advantage of using a distributor in that it can hold more sealant than a heating unit and would not have to be refilled as often. The use of pour buckets to fill cracks requires continual refilling of the pour buckets with bituminous material. This also requires that at least 2 crew members use pour buckets to apply the sealant, so that an adequate application of sealent into the cracks is achieved.

From the field observations there appears to be an advantage of using a heating unit or a distributor with a hand held nozzle over the use of pour buckets. One advantage of using a nozzle for application is that there is more control and accuracy in placing the sealant in the crack. With the use of a nozzle, the sealant can be put directly into the crack and the flow of material is more easily controlled. Pour buckets only allow materials to be placed near the crack and there is no flow control with pour buckets.

Another disadvantage of using pour buckets is that when full of sealant they weigh 25 to 30 lbs. This is very tiring for crew members to use

especially since pour buckets are used with one arm only. One crack sealing crew using pour buckets told the observer they used pour buckets because the bituminous sealent was freezing in the nozzle. This crew was from the Fort Wayne subdistrict which is located in the northeast portion of the state.

Although, in general, the use of a heating unit with a hand held nozzle may be more effective in applying the sealant, there may be a problem with freezing of the nozzles in the northern half of the state. Eight of 10 subdistricts located in the northern third of the state surveyed recorded that they use either a distributor or a heating unit with a hand held nozzle. Of those eight, four are low productivity, higher cost subdistricts. Of the two that recorded using pour buckets, one is a high productivity - lower cost subdistrict while the other is near the lower limit (boundry between average and high productivity groups) determined using the MIS program.

From the field observations and the data analysis it appears that subdistricts in the lower two thirds of the state should use a heating unit when applying the sealant. For subdistricts located in the upper third of the state, where cooler temperatures are common, pour buckets may be

advantageous to use. Further research on pour bucket use is required before any definite conclusion can be recorded. However, if pour bucket use in the upper third of the state is found to increase productivity of crack sealing, individual productivity levels (groupings) should be established for the upper third subdistricts and the lower two third subdistricts due to the fact that two distinctive methods of crack sealing would be used.

The last difference in equipment use for crack sealing observed was in the application of the cover aggregate (sand) to the road surface. Some subdistricts use a dump truck with a salt spreader attached. As the truck backs up, the sand is spread mechanically onto the sealed cracks. The other method observed uses a dump truck loaded with sand and two crew members shoveling the sand onto the cracks recently filled with bituminous sealant.

Field observations revealed that the use of a salt spreader attached to the dump truck was quite effective in covering the sealed cracks. A greater quantity may or may not be used by this method (with respect to the men shoveling), yet it replaces two crew members. Therefore, it is suggested that the sand be placed on the sealed cracks by use of a salt spreader attachment connected to a dump truck.

3. Materials

Material preparation varied among subdistricts, particularly in the procedure used in heating the bituminous sealant for application. It is suggested that the use of one to two hours of overtime for one man be used so that the sealant is at the proper temperature for sealing and the sand is loaded on the truck before regular working hours. This would decrease down time during regular shift hours when all crew members must be paid.

4. Crew Attitudes

The last item that affecting productivity of a subdistrict is the attitude of crew members toward performing a crack sealing operation. Most crews visited believed that crack sealing was a waste of time and money, and consequently, the job performance both quantitatively and qualitatively suffered. Crews who agreed that the sealing of cracks adds to pavement life tended to be in the high productivity group.

For productivity levels to increase, a lead worker or unit foreman who understands the benefits of crack sealing must accompany a crack sealing crew. Training of the crew on the benefits of proper crack

sealing may improve their attitude and subsequent performance.

A last observation that may not necessarily increase productivity but may improve the quality of crack sealing involves the use of curved or "U" shaped sqeegees in place of straight squeegees. More material can be placed directly in the crack instead of on the road surface by use of curved squeegees. All subdistricts visited used straight squeegees when crack sealing.

CHAPTER 4

MAINTENANCE ACTIVITY CHECKLISTS

4.1 Introduction

A major goal of this research was to identify the factors that influence routine maintenance productivity for shallow patching and crack sealing activities performed by the IDOH maintenance crews. After the identification of these factors, a checklist was developed. This checklist can be used at the district or at the central office level to determine the reason for differences in productivity of shallow patching and crack sealing activities among subdistricts during a given time period. The checklist can also be used by the individual subdistricts to evaluate their performance.

The checklist is used in accordance with the MIS [3] information and other data supplied by subdistrict superintendents for a specific activity and time period. The information supplied by the subdistricts could be added to the data tape so that all information is contained on the MIS output.

4.2 Use of the MIS with the Checklist

The management information system (MIS) provides management and subdistrict superintendents with labor, material, and unit cost information, pertaining to a specific activity, necessary in classifying the subdistricts into production groups. These production groups are low, average and high production and are based on unit cost. The MIS calculates the boundaries for each production group by first calculating the statistical mean and standard deviation of the unit cost per production unit on the basis of the thirty-seven subdistricts. The production group boundaries are established by using plus or minus one standard deviation from the overall mean. For example, subdistricts that have a unit cost less than one standard deviation from the overall mean are placed in the high production group. Subdistricts that have a unit cost greater than one standard deviation from the overall unit cost mean are placed in the low production group. All other subdistricts that fall between plus or minus one standard deviation from the overall unit cost mean are placed in the average production group.

The MIS also produces information on the average crew size and the amount of time shallow patching or crack sealing was performed on interstate versus other state roads for each subdistrict.

All information produced by the MIS can be readily used by management, subdistrict superintendents, and even unit foremen. The MIS also produces bar chart comparisons of all subdistricts so that superintendents and managers of each subdistrict are able to see how their subdistrict compares to others. Although the MIS produces a great deal of data needed in the evaluation of productivity, other data are needed to fully understand routine maintenance productivity.

4.3 Use of Other Data with Checklist

Data on equipment use, time delays, and supervision are not recorded on tape for analysis by the MIS, and therefore must be provided by the subdistrict superintendents and unit foremen. The information can be easily kept track of by tally sheets filled on each day. Such information is essential in correctly recording and evaluating subdistrict productivity. What method of compaction was used on a shallow patching operation, is one such example of information that should be made available to a manager so that he can approximately evaluate the productivity levels of his crews.

4.4 Use of the Checklists for Shallow Patching and Crack Sealing

Checklists were developed for shallow patching and crack sealing. The checklists incorporate findings from the statistical analysis of each activity, the survey information, and the field observations.

The checklists provide a means of comparing productivity groupings of subdistricts as well as giving reasons why differences in productivity exist. A low productivity subdistrict could be compared with an average or high productivity level (groupings determined by the MIS) to determine the impact of differences in procedures and equipment use. Depending on the set procedure for a specific activity steps could then be taken to improve the production of a low productivity subdistrict. A high productivity subdistrict, on the other hand, may not be following the set work procedure established for a specific activity and their quality of work may not be up to standard. The checklist will assist managers to make sure that appropriate procedures are being followed by the maintenance crews.

One improvement that the IDOH Maintenance Division should make is the addition of equipment use data, contained on the crew day cards, to the data base tape. This would provide an accurate account of equipment use

that could be added to the MIS data base so that equipment reports could be produced along with the information on materials and labor already provided by the MIS.

Following each checklist is a description of each item and how this item may affect the productivity of the maintenance activity. Most of the items on each checklist are to be checked as "Yes" or "No." There are a few items under the category "Other" that require either a frequency or percentage response.

4.5 Description of Shallow Patching Checklist

In Figure 4.4.1, the checklist for shallow patching is presented. A description of each of the items included in the checklist is given in the following sections.

A. Field Supervision

1. Presence of Unit Foreman

The presence of a unit foreman at the job site may cause the production of a subdistrict to increase or decrease. A statistical analysis of the subdistrict survey data that pertained to this question showed that there was no significant difference between high and low productive subdistrict groups. However, field observations indicated that a unit foreman's

A. Field Supervision

Y N

1. Presence of unit foreman during field work
2. Prior training of crew members

B. Crew Size

1. Average crew size less than six
2. Average crew size greater than or equal to six
3. Age of crew members greater than forty

C. Materials

1. Hot plant mix used for shallow patching
2. Stockpiled mix used for shallow patching
3. Adequate temperature of mix at the time of application
4. Adequate workability of mix
5. Application of tack coat to patching area

D. Equipment

1. Method of mix compaction
   a. Use of hand tamp
   b. use of truck wheel
   c. Use of vibratory compactor
   d. Use of mini-roller

E. Work Practices

1. Pre-patch preperation of patching area
   a. Manual sweeping or cleaning of patch area
   b. Mechanical sweeping or cleaning of patch area
   c. Removal of loose material from patch area
   d. Drying of patch area
   e. Squaring of sides of the patch area
   f. Application of tack coat to patch area
2. Continuously moving operation
3. Stopped operation
4. Quality assessment of work during patching
5. Amount of down time experienced per patching day
   a. Less than or equal to one hour per day
   b. Greater than one hour per day

F. Other Areas

1. Amount of road patching performed on:
   a. Interstate
   b. Other state roads multi-lane
   c. Other state roads two lane
2. Percentage of time adequate mix temperature could not be maintained during this time period (refer to Section C3)

Figure 4.4.1 Shallow Patching Checklist.

presence on the job site promoted more work from the crew members. However, production may be lower due to the fact that more care and better patching techniques were applied. Pre-patch preparation of holes, a higher quality compaction method, and careful checking of the completed work usually occur when a unit foreman accompanies the patching crews.

2. Prior Training of Crew Members

Production levels of subdistricts may vary depending on the level of training of the crew personnel. Those crews containing new members take extra time for explaining methods to new members. Use of the heavy equipment takes skill that is only acquired through practice. There may be some crew members that do not fully comprehend the benefits of performing specific parts of the patching operation. For instance, some crew members may believe that running over a patch with a track wheel will compact the patch area as well as a mechanical compactor. Again, some crew members may tend to believe that pre-patch hole preparation is unnecessary and therefore may skip this part of the patching process. For instance, only one subdistrict observed performed pre-patch hole preparation.

This subdistrict crew observed was supervised by a unit foreman. Most crew members who are well informed perform the complete patching process thereby increasing the quality of shallow patching work.

B. Average Crew size

1. Average Crew Size Less than Six

Subdistricts that have patching crew sizes less than six may be a high productivity subdistrict. Using the MIS, the average crew size for the 1982-83 fiscal year was found to be approximately 6 men. This activity is labor intensive and small crew sizes decrease the cost of patching. The recommended crew size was determined to be five or six (depending on the type of patching that is to be performed) [see section 4.4.3] from field observations made in the present study.

2. Average Crew Size Greater than or Equal to Six

Subdistricts that use patching crew sizes of six or more may tend to be low productivity subdistricts, as the additional manpower may be underutilized. Field crews observed that had more than six members were from a low productive

subdistrict. The recommended crew size for shallow patching is five to six.

3. Age of Crew Members

Shallow patching is a physically intensive activity. Crews that contained members over 40 years of age were generally observed to have a lower productivity than crews that contained younger personnel. Therefore, a difference in productivity levels among subdistricts may be experienced due to age differences among crews.

C. Materials

1. Hot Plant Mix Used for Shallow Patching

Subdistricts that use hot plant mix for patching may have a lower productivity level than subdistricts that use stockpiled mix for patching due to greater "down time" experienced with the use of hot plant mix. Down time refers to the part of the work day when crew members receive pay but no actual patching is performed. Down time is experienced by subdistricts that use hot plant mix when retrieving and purchasing the mix. This is done at the beginning of each work day. One or two crew members are sent to the plant to purchase the mix. The average down

time experienced by subdistricts that use hot plant mix is approximately 1 to 1 1/4 hours, but can be up to 2 1/2 hours depending on the location of the patching site, the distance from the patching site to the mix plant, and whether or not the mix plant is producing the correct type mix at the time. Some drivers (crew members that pick the mix up) are sent from one mix plant to a second mix plant before actually obtaining the patching mix.

2. Stockpiled Mix Used for Shallow Patching

Subdistricts that use stockpiled mix for shallow patching may have higher productivity levels than subdistricts that use hot plant mix for patching due to less down time experienced when stockpiled mix is used.

Stockpiled mix is stored at the unit garages (see Figure 3.3.6) so there is no travel down time experienced. The stockpiled mix is put through a porta-patcher (see Figure 3.3.5). This is a device that heats the stockpiled mix to a workable temperature. This temperature varies depending upon the formula of the stockpiled mix but is usually between 120-160^{o} F. There is some down time associated with the

heating of the mix, however it is usually less than the down time experienced with hot plant mix use.

3. Adequate Temperature of Mix at Time of Application

The workability of the mix is directly related to the temperature of the mix. Those subdistricts that are able to maintain mix temperatures within the recommended range for the particular type of asphalt mix used [13] may have higher productivity levels than those subdistricts unable to maintain workable mix temperatures.

Some subdistricts make use of a "hot box" which is a mix bin trailer containing warmers that maintain the temperature of the mix (see Figure 4.5.1).

The workability of the mix decreases as the mix temperature decreases. The mix will begin to harden (set up) and become more difficult to place and compact as it cools. This leads to lower productivity levels as well as lesser quality patching. Regreasing or reoiling of shovels, rakes, and compacting tools becomes more frequent when the mix cools off. Field

Figure 4.5.1 Example of a Hot Mix Bin.

observations showed that unheated mix bins usually do a better job of retaining the temperature of the mix than tarp covered trucks because the mix may be obtained from the mix bin through a small opening at the rear of the trailer. Less of the mix is exposed to the air and therefore does not cool off as rapidly.

Item C3 of the patching checklist shown in Figure 4.4.1 refers to all patching peformed during the time period being analyzed. Therefore, if the mix was at an adequate temperature for most of the patching done during the time period in question, the answer to this question would be "Yes".

4. Adequate Workability of Mix

Characteristics of the mix can lead to differences in productivity. Mix gradation, asphalt content and grade, and temperature of the mix all affect the workability of the mix in the field. Differences in productivity levels associated with mix characteristics are usually due to compaction of the mix. Compaction difficulties will increase or decrease depending on the mix characteristics.

From the field observations, it was found that various mix designs are used for shallow patching. Samples of the patching mix were taken at each field observation. From visual observation of the samples, it was found that each mix was different. Top grain sizes of the mixes varied from sand size particles to a chip size particle. Unfortunately, sample sizes collected at each site were too small to run any lab tests for specific gradation and asphalt content analysis.

From talking with the crew members during the field observations, it was found that mix characteristics change from day to day in the case of hot plant mix and the crew members must take what the plant gives them. That is, there was no mention of any plant producing a second mix batch for a crew even if the quality of the first batch was questionable.

5. Application of Tack Coat to Patching Areas

Subdistricts that apply a tack coat to the patching area before mix is placed and compacted may have lower productivity than those subdistricts that do not apply a tack coat, because of the additional time required.

Application of tack coat is generally associated with large area patches (areas greater than 3-4 square feet in area). For patch areas smaller than 3-4 square feet, the application of a tack coat is rare.

Information produced by the MIS show that some subdistricts apply tack coats when shallow patching, however, the application of a tack coat to patching areas was never observed during the field observations.

D. Equipment

1. Method of Mix Compaction

a. Use of a Hand Tamp.

Use of a hand tamp, a hand held tool that has a square, flat metal plate mounted perpendicular to the handle, is the most common method of compaction used in shallow patching (see Figure 3.3.3). There are different levels of compaction effort associated with the use of a hand tamp. Compaction effort can range from little more than that produced by gravity to powerful two handed strokes repeatedly applied. There is also a variation of

compaction levels throughout the work day. Compaction effects are greater at the beginning of the work day than at the end of the work day. Crew members tire as the work day continues and their compaction effects decrease in the afternoon. There are portions of the patch area(s) that are never compacted. An example of this was seen while observing a patching crew from the Fort Wayne subdistrict. Large portions of the patch areas were never compacted by the maintenance crew. These areas were eventually compacted by traffic on the road, however this is not a recommended method of mix compaction due to the uneven compaction that results from traffic tires. Also, the average life expectancy of patches that have been compacted using a hand tamp (and relying on traffic to finish compaction) was reported as approximately two months [17].

b. Use of Truck Wheel

This method of compaction consists of running a vehicle over the patch area. Subdistricts that use this method may have higher productivity levels than other

subdistricts due to the quickness of compacting the patch areas.

This compaction method was used by a crew from the Bloomington subdistrict. In this case, a crew cab pickup was used to compact large patches. However, life expectancy of the patch using this method of compaction was reported to be approximately 2 months [17].

c. Use of a Vibratory Compactor

This method of compaction uses a wacker (vibratory compactor) to apply repeated impacted loads to the patch area (see Figure 3.3.4). Subdistricts that use this method of compaction usually have lower productivity levels than those subdistricts that do not make use of a vibratory compactor. The machine is heavy and somewhat awkward to use. Consequently its use decreases the productivity. However, the life expectancy of the patch was 7 or more months [17]. This compaction method was used by a crew from the Crawfordsville subdistrict. The wacker was used on three large area patches.

d. Use of a Mini-Roller

This last method of compaction uses a pup roller to compact the patch area (refer to Figure 4.5.2). Subdistricts that may use this method of compaction would have lower productivity levels than those subdistricts that use hand tamp and/or truck wheel compaction methods. The life expectancy of the patch was reported to be 7 or more months [17].

This compaction method was never observed during this study. However, one crew that was observed commented that they would prefer the use of a mini-roller over a wacker but their unit garage was not equipped with a mini-roller.

E. Work Practices

1. Pre-patch Preparation of Area

There are five items listed for this category. Subdistricts that do any of the five pre-patch preparation items usually have lower productivity than those subdistricts that do no pre-patch preparation of the patching area. Those subdistricts that do all five items

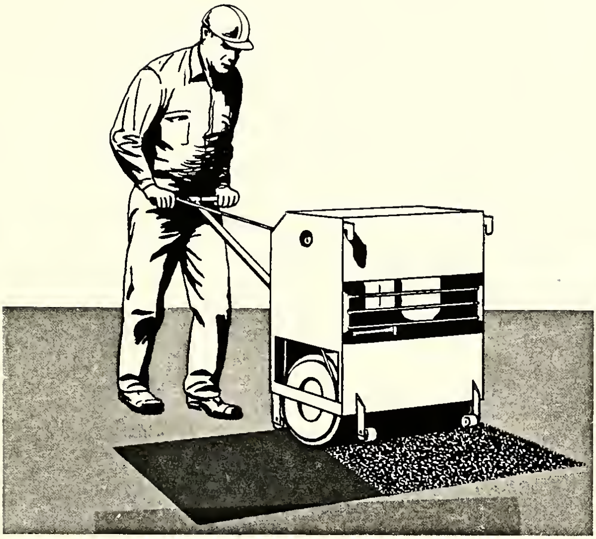


Figure 4.5.2 Patch Compaction by the Use of a Mini-Roller.

usually have lower productivity levels than those that do a few of the items. Items 1 through 3 can be accomplished through different means (by hand or mechanically) and therefore may change the productivity of a subdistrict, depending on the method used, by a varying amount. Items 4 and 5 require more machinery and possibly more crew members and will therefore change the productivity of a subdistrict by a noticeable amount. It was found, in a study conducted by the Cold Engineering Regions Laboratory, that pre-patch preparation of the patching area in accordance with mechanical compaction increases the life expectancy of the patch [17].

2. Continuously Moving Operation

An operation in which the equipment and crew move down the road filling holes without stopping for a long period of time (<30 minutes) is considered to be a continuously moving operation. Subdistricts that perform this type of patching operation may have different productivity levels than those subdistricts that perform a stopped operation. The continuous patching operation usually lends itself to higher productivity levels. However, a crew

that is performing a stopped operation may place a large quantity of mix in one area and would have a high production level due to the production unit used (cost per ton of mix placed). In a continuous operation, there may be a small time period when the equipment is actually stopped (usually to allow part of the crew to catch up with the rest of the crew) but it does not remain idle for long period of time. With this type operation, equipment is located in the traffic lane being repaired and travels down the road at a slow speed.

3. Stopped Operation

A stopped operation is one where the vehicles are located in one area for a long period of time (>30 minutes). This usually occurs during large area patching (>3-4 sq.ft.). Some of the vehicles may be stopped in the roadway while others are parked off on the shoulder of the road. Subdistricts that have to perform this type of operation more frequently than other subdistricts usually show lower productivity levels. Associated with larger area patching is the use of a wacker or some means of mechanical compaction. Pre-patch preparation is usually performed with larger

area patching. Both procedures increase the amount of time and personnel needed to complete the patching.

4. Quality Assessment of Work during Patching

Those subdistricts that check their work during patching and make corrections to improperly patched areas will usually have lower productivity levels than those subdistricts that make no assessment of the work performed.

Quality assessment of work includes items such as whether or not the patch is level, adding more mix to a patch after compaction, returning to areas where some holes were not patched or more compaction is needed and so on. These steps require additional time and therefore add to the cost of the patching operation.

5. Amount of Down Time Experienced per Day

The average down time in shallow patching experienced by the 37 subdistricts in Indiana (for 1983-84) was found to be approximately 1.0 to 1.1 hours/day, as discussed in Chapter 3. Down time consists of travel time to and from the job site, travel time to pick up mix from

plant, and equipment failure. Subdistricts with higher than usual down time generally have lower productivity levels, because of the wasted work time.

F. Other Areas

1. Type of Road

Three types of road are listed in this item. Each type of road has associated with it differing daily traffic levels. Therefore, if certain subdistricts perform the majority of their patching on one particular road type, they may experience different productivity levels than subdistricts that do a majority of their work on another road type or those that patch on all three an equal percentage of time. A space is provided to place the percentage of time patching is performed on each road type for this time period. Percentage differences greater than 20-25% between road types can be considered to be truly different.

2. Percentage of Time Adequate Mix Temperature Could not be Maintained

The percentage of time that adequate mix could not be maintained during the time period in question should be recorded. This will allow management and subdistrict superintendents to determine if inadequate mix temperature experienced by subdistricts is excessive or not. The percentage at which inadequate mix temperature experienced is excessive should be decided by management and subdistrict superintendents.

4.6 An Example of the Use of the Shallow Patching Checklist

In this section, an example of the use of the shallow patching checklist is presented. Figure 4.6.1 contains the completed checklist for the Crawfordsville subdistrict. Here, the information to complete the checklist came from the survey data, the field observation of a Crawfordsville subdistrict crew, and the results produced by the MIS for 1983 fiscal year maintenance data. It was assumed that the one field observation was representative of the work performed by most of the maintenance crews in the Crawfordsville subdistrict.

A. Field Supervision

Y N

1. Presence of unit foreman during field work
2. Prior training of crew members

B. Crew Size

1. Average crew size less than six
2. Average crew size greater than or equal to six
3. Age of crew members greater than forty

C. Materials

1. Hot plant mix used for shallow patching
2. Stockpiled mix used for shallow patching
3. Adequate temperature of mix at the time of application
4. Adequate workability of mix
5. Application of tack coat to patching area

D. Equipment

1. Method of mix compaction
   a. Use of hand tamp
   b. use of truck wheel
   c. Use of vibratory compactor
   d. Use of mini-roller

E. Work Practices

1. Pre-patch preperation of patching area
   a. Manual sweeping or cleaning of patch area
   b. Mechanical sweeping or cleaning of patch area
   c. Removal of loose material from patch area
   d. Drying of patch area
   e. Squaring of sides of the patch area
   f. Application of tack coat to patch area
2. Continuously moving operation
3. Stopped operation
4. Quality assessment of work during patching
5. Amount of down time experienced per patching day
   a. Less than or equal to one hour per day
   b. Greater than one hour per day

F. Other Areas

1. Amount of road patching performed on:
   a. Interstate
   b. Other state roads multi-lane
   c. Other state roads two lane
2. Percentage of time adequate mix temperature could not be maintained during this time period (refer to Section C3) 40-50

Figure 4.6.1 A Shallow Patching Checklist Completed for the Crawfordsville Subdistrict.

Part A of the checklist was completed using the field observation information. A unit foreman was present at the patching site and the crew members were experienced in the shallow patching operation. Part B of the checklist was completed using the MIS results and also using the field observation information. The average crew size for the Crawfordsville subdistrict (for shallow patching), for the 1983 fiscal year, was eight. The number of crew members present during the field observation was seven. There were three crew members over the age of forty present during the field observation. The unit foreman, the driver of the dump truck that contained the mix, and a general laborer were all over forty years of age. Part C of the checklist was completed by the use of the field observation information, the survey data, and the MIS results for fiscal year 1983. Hot plant mix was used as the patching material. Temperature of the mix decreased as the day went on because the mix was not placed in a hot bin. The mix was placed in a dump truck and covered with a tarp. The MIS showed that for the majority of shallow patching work done by the Crawfordsville subdistrict, hot mix was used for the patching material. Workability of the mix decreased as the temperature of the mix decreased.

Part D of the checklist was completed by the use of the field observation information. The mix was compacted with a vibratory compactor and hand tamps (used to form

shoulder edge). Section E of the checklist was completed from the field observation information. Pre-patch preperation of the patching area was performed by the patching crew. The patch area was hand swept and loose debris removed from the patch area by the patching crew.

The operation used to patch this road was a stopped operation. Quality assessment of the work was made by the unit foreman and patch deficiencies were corrected by the crew. The amount of down time experienced during the day was approximately one and a half hours. Picking up the mix at the batch plant was the cause of this down time. Section F of the checklist was completed from data obtained through the survey and field observation data. The patch work was performed on a two lane road with moderate truck and car traffic associated with it. The percentage of time the mix temperature was not adequate for patching was approximately forty to fifty percent.

From the answers given on the checklist, the Crawfordsville subdistrict should be a high cost subdistrict. The results of the MIS run on 1983 shallow patching data showed that the Crawfordsville subdistrict was indeed a high cost subdistrict. With this example, the checklist and the MIS results agree. It is felt that the checklist can be used to identify the areas that cause some subdistricts to be high cost and others low cost.

4.7 Description of the Crack Sealing Checklist

In Figure 4.7.1, the checklist for crack sealing is presented. A description of each of the items included in the checklist is given in the following sections.

A. Personnel

1. Presence of Unit Foreman During Field Work

The presence of a unit foreman at the job site may cause the production of a subdistrict to increase or decrease. A statistical analysis of the subdistrict survey data pertaining to this question showed that there was no difference among subdistricts. However, field observations showed that a unit foreman's presence on the job site promoted more work from the crew members. Production may be lower due to additional time needed to complete sealing procedures that are followed when a unit foreman is present. Crews are more likely to stop the sealing procedure to go back and seal a crack that had been missed during the initial pass when a unit foreman is present.

A. Field Supervision Y N

1. Presence of a unit foreman during field work
2. Prior training of crew members

B. Crew Size

1. Average crew size less than nine
2. Average crew size greater than or equal to nine

C. Materials

1. Adequate temperature of the bituminous sealer maintained at the time of application
2. Adequate drynese of the cover aggregate during application

D. Equipment and Work Practices

1. Use of an air compressor on most job sites
2. Application of bituminous sealer
   a. By use of a distributor
   b. By use of a tar kettle
   c. By use of a pour bucket
3. Application of cover aggregate
   a. Application by hand (shovels)
   b. Application by use of a salt spreader on truck
4. Application of sealer to cracks near the centerline of the pavement

E. Other Areas

1. Percentage of work days that the sealer was not at an adequate temperature at the time of application
2. Road type sealing was performed on
   a. Interstate
   b. Other state road multi-lane
   c. Other state road two lane
3. Amount of cracking on road surface per lane mile for the majority of the roads sealed
   a. Light
   b. Moderate
   c. Heavy

Figure 4.7.1 Crack Sealing Checklist.

2. Training of Crew Members

Production levels of subdistricts may vary depending on the training of crew members. Those crews containing new crew members also take longer time familiarizing new members with the equipment and sealing procedure.

It was found from the field observations that there are many crew members who feel crack sealing is a waste of time, money and will not appreciably add to the life of the pavement. Crew members who believed crack sealing was beneficial showed a higher productivity level and crack sealed their roads in a more complete manner (indicating that very few cracks remained unsealed) than crew members who believed crack sealing was a waste of time.

B. Crew Size

1. Average Crew Size Less Than Nine

Subdistricts that use sealing crew sizes of less than nine may be higher productivity subdistricts. As are most maintenance activities, crack sealing is a labor intensive activity and smaller crew sizes decrease the

cost of crack sealing. The recommended crew size was determined to be eight or nine (depending on the crack sealing procedure performed) from the field observations.

2. <u>Average Crew Size Greater Than or Equal to Nine</u>

Subdistricts that use sealing crew sizes greater than nine may be low productivity subdistricts. This depends on the sealing method used in the field. That is, what grouping of equipment is used to crack seal, use of personnel, weather temperature, etc. It was found from the field observations that crew sizes greater than nine workers usually causes at least one worker to be present in a nonproductive state.

C. Materials

1. <u>Adequate Temperature of the Bituminous Sealer</u>

Temperature of the sealer is very important in relation to flow of the sealer and the spreadability of the sealer into the cracks. Field observations revealed that acceptable sealer temperature range is from 120 - 170^{o} F.

Those subdistricts that are able to maintain sealer temperatures within this temperature range (this temperature range may vary depending on the type of sealer material used). may have higher productivity levels than those subdistricts unable to maintain workable sealer temperatures [13].

Some subdistricts located in the northern third portion of Indiana have problems with the sealer freezing in the wand portion of a heating unit and have therefore switched to using pour buckets for sealer application. Fort Wayne was one such subdistrict that now uses pour buckets instead of using a distributor or heating unit with a nozzle applicator for application of sealant into the cracks. The Fort Wayne maintenance crews were having problems with the sealant freezing in the nozzle. Also, some subdistricts have problems with equipment failure.

2. Adequate Dryness of Sand During Application

The dryness of sand (cover aggregate) at the time of application may affect the productivity of the sealing crews. This depends on the method of application of the sand and the

moisture content of the sand. Those subdistricts that experience moister sand may have lower productivity levels.

D. Equipment and Work Practices

1. Use of an Air Compressor

Subdistricts that use a air compressor when crack sealing may have lower productivity levels than those subdistricts that do not use an air compressor. The use of an air compressor to clean the cracks of debris before sealing requires the use of one extra crew member (a nozzle operator). Figure 3.4.4 gave an example of cleaning the crack with the use of an air hose and a broom. On a crew with an air compressor, the flagman may then become the driver of the vehicle that pulls the air compressor, as the vehicle itself preempts the need for a flagman.

2. Application of Sealer

a. By use of a Distributor

Those subdistricts that use a distributor may have lower productivity levels than those subdistricts that do not

use a distributor. This is dependent on how the distributor is used. If the spray bar is used to apply the sealer to the cracks (as in a surface treatment), then productivity levels may be low. Use of a distributor in this manner would use greater quantity of sealer per lane mile and more crew members to distribute the sealer into the cracks. Figure 3.4.6 shows a typical distributor used in the field.

If a distributor is used where a wand applicator is used instead of the spray bar, then productivity of the crews should not vary much from crews that use a heating unit.

b. <u>Use of a Heating Unit with a Wand Applicator</u>

Use of a heating unit with a wand applicator is the most common way of applying the sealer to the cracks (see Figure 4.4.7). Subdistricts using this method of sealer application usually experience average to high productivity. Northern subdistricts may have lower productivity levels due to the colder

weather. The sealer may freeze in the wand portion of the heating unit.

c. <u>Use of Pour Buckets in Sealer Application</u>

Subdistricts using pour buckets may have higher productivity levels than subdistricts using other methods of sealer application, especially in the northern subdistricts. Some northern subdistricts use pour buckets to avoid problems with sealer freezing in the wand portion of the heating unit or distributor. Pour buckets are not as accurate in applying sealer to the cracks as a wand and there is no flow control on the pour buckets. An example of a pour bucket was given in Figure 4.4.8.

Therefore, for a specific road, a crew using pour buckets will most likely use more sealer per lane mile then a crew that uses a heating unit with a wand applicator. Pour buckets are not as efficient as a heating unit for sealer application, yet they are well suited for cold weather regions.

3. Application of Cover Aggregate (Sand)

a. Application by Hand

Those subdistricts that apply the cover aggregate onto the sealed cracks by use of shovels may have lower productivity levels than those subdistricts that apply sand mechanically. Subdistricts that use crew workers to shovel the sand onto the sealed areas normally have larger crew sizes. At least two extra crew members are needed to apply the sand in this method. Also, production at the end of the day may be lower than at the beginning due to the strenuous type work involved. The actual sealing process may have to stop so that the sand applicators can catch up to the rest of the crew which also lower production.

b. Application by Use of a Salt Spreader on Truck

Those subdistricts that use a salt spreader on the back of the dump truck or "do-all" to apply the cover aggregate may experience higher productivity levels than those who use shovels. This method of

application eliminates at least two crew members from the sealing process (those who shovel sand from the truck onto the road). The sand application by truck is able to keep up with the sealing process where the other method is dependent on the pace of the crewmen with the shovels.

There does not appear to be much more sand used in this process compared to sand application by hand. Also, the quality of work is equal to, if not greater than, that resulting from hand shovelling.

4. Application of Sealer to Cracks Near the Centerline of the Pavement

Certain subdistricts do not seal cracks that are near the centerline of the pavement to avoid covering up the pavement markings. These subdistricts may have higher productivity levels due to the use of less sealer, less sand (in some instances), and having less area to seal.

In most instances, centerline cracking is not severe and therefore production levels change little. There are, however, some subdistricts where centerline cracking is prevalent and production levels there are

noticeably different, depending on whether the centerline cracks are sealed or unsealed.

E. Other Areas

1. Maintenance of Adequate Temperature

An estimate of the percentage of work days that the sealer was not at an adequate temperature is necessary to evaluate the impact of this factor on productivity. This percentage is calculated in the following manner.

$$\text{Percentage} = \frac{n}{N}\ 100\ \%$$

where :

n = number of inadequate sealer temperature days

N = total number of sealing days

If a high percentage is recorded, the subdistrict may try an alternative sealing method or sealing equipment.

2. Road Type

A percentage should be given for each road type on which sealing was performed. Subdistricts that have to seal cracks on

Interstate and multi-lane roads may have different productivity levels than those subdistricts that seal mainly two lane roads. This stems from safety procedures and the traffic density associated with each road type. In general, as traffic density increases, sealing productivity decreases.

3. <u>Amount of Cracking on Road Surface per Lane Mile</u>

The three categories listed are general and therefore may be subjected to many interpretations. A general guideline to follow in choosing a category is as follows:

Light - a road surface that has 3-6 cracks in a twenty-four foot length (of one lane). Cracking is usually transverse or longitudial (reflection cracking).

Moderate - a road surface that has 6-10 cracks in a twenty-four foot length (of one lane). Cracking includes transverse, longitudial, and diagonal.

Severe - a road surface that has more than 10-12 cracks in a twenty-four foot length (of one lane). Cracking includes all types listed previously plus alligator cracking. Cracking is

prevalent in the wheel paths.

Subdistricts that seal older, badly worn roads containing a high number of cracks per lane mile will show lower production levels, yet may have a very efficient and hard working sealing crew. Therefore, if the roads sealed by the subdistricts were accurately classified, a more sound evaluation of the productivity of a subdistrict sealing program could be made.

4.8 An Example of the Use of the Crack Sealing Checklist

An example of the use of the crack sealing checklist is presented in this section. Figure 4.8.1 shows a completed crack sealing checklist for the Fort Wayne subdistrict. Information to complete the form came from field observations of this subdistrict, the survey data, and the results of the MIS run on 1984 fiscal year crack sealing data. Field observation data are from one field visit only. However, for the purpose of this example it can be assumed that this one field observation is representative of typical work practices performed by maintenance crews in this subdistrict.

Section A of the checklist was completed using the field observation data. A unit foreman was present at the

	Y	N
A. Field Supervision		
1. Presence of a unit foreman during field work	✓	
2. Prior training of crew members		✓
B. Crew Size		
1. Average crew size less than nine		✓
2. Average crew size greater than or equal to nine	✓	
C. Materials		
1. Adequate temperature of the bituminous sealer maintained at the time of application	✓	
2. Adequate dryness of the cover aggregate during application	✓	
D. Equipment and Work Practices		
1. Use of an air compressor on most job sites	✓	
2. Application of bituminous sealer		
a. By use of a distributor		✓
b. By use of a tar kettle	✓	
c. By use of a pour bucket	✓	
3. Application of cover aggregate		
a. Application by hand (shovels)	✓	
b. Application by use of a salt spreader on truck		✓
4. Application of sealer to cracks near the centerline of the pavement		✓
E. Other Areas		
1. Percentage of work days that the sealer was not at an adequate temperature at the time of application		
2. Road type sealing was performed on		
a. Interstate		
b. Other state road multi-lane		
c. Other state road two lane	✓	
3. Amount of cracking on road surface per lane mile for the majority of the roads sealed		
a. Light		
b. Moderate	✓	
c. Heavy		

Figure 4.8.1 A Crack Sealing Checklist Completed for the Crawfordsville Subdistrict.

crack sealing site. However, the crew was being trained the day they were observed.

Section B of the checklist was completed using the MIS results and the field observation data. The average crack sealing crew size for fiscal year 1984 was eleven and the number of crew members present during the field observation was nine.

Section C of the checklist was completed using the field observation data. Adequate temperature of the sealer was maintained and the cover aggregate used was dry.

Section D of the checklist was completed using the field observation data and the survey data. An air compressor was used to clean the cracks and a distributor was used to apply the sealant into cracks. The cover aggregate was applied by hand. Two crew members using shovels spreaded the covering of aggregate over the sealed cracks. Sealant was not placed in cracks near the centerline to avoid cover the pavement markings.

Section E of the checklist was completed by using the field observation data. Question one could not be answered from the data aviable. The road sealed was a two-lane and had light to moderate traffic on it. The amount of cracking per lane-mile was found to be moderate.

From the checklist answers, Crawfordsville should be an average to high cost subdistrict. The crack sealing field observation was performed during the 1984 fiscal year. The MIS results for 1984 fiscal year data placed Crawfordsville into the high cost subdistrict grouping.

CHAPTER 5

SUMMARY AND RECOMMENDATIONS

5.1 Summary

The use of the Management Information System (MIS) developed in Phase I of the study [3] along with the maintenance activity checklists developed in Phase II can assist managers and subdistrict superintendents in identifying areas for routine maintenance productivity improvement. The method used in this phase to determine the factors that influence productivity of pavement patching and sealing activities can be used for any other routine maintenance activities.

A statistical analysis of the crew day card data produced by the MIS, for a particular activity, can be performed to identify the primary variables that affect the unit cost the most. A survey can be developed to obtain information on down time experience with the activity as well as obtaining information that is not included on the crew day card data tape. Field observations of the activity will then be needed to identify specific factors that cause difference in

productivity among subdistricts. Written reports and slides should be taken at each field observation. The final step would be to construct a checklist from the information gathered from the above steps so that managers and superintendents can detect the reasons for the performance of individual subdistricts.

5.2 Recommendations

From the study conducted, it is recommended that the crew size for a shallow patching crew be six. Also, efforts should be made to minimize the down time experienced when using a hot plant mix for patching. Possibly, it can be arranged to pay one man certain hours of overtime a day to pick up the hot mix before actual work day begins. If down time cannot be eliminated, some use of the idle manpower, such as pre-patch preparation of patching area, should be practiced.

Mechanical compaction of the patching mix should be used whenever possible to extend the life of the patch. Compaction of the mix is the most important part of shallow patching.

The recommended crew size for crack sealing is nine. This crew size was found to work the best in the field. An air compressor should be used to clean the cracks in crack sealing operation. This is to avoid the formation

of pressure ridges about the cracks. It was found through field observations that it may be desirable for northern subdistrict to use pour buckets to apply the sealent to cracks during cooler months in order to achieve a higher level of productivity.

A salt spreader on the back of a dump truck should be used to apply the cover aggregate during the sealing operation. Since equipment and equipment use play an important role in routine maintenance productivity, equipment records should be transferred from the crew day cards onto the data tape for evaluation by the MIS.

Use of the checklists provided will allow managers and subdistrict superintendents to evaluate equipment use, personnel use, and material use. The information needed to complete the checklist is easily obtainable and should therefore be used to pinpoint areas for improvement of productivity of routine maintenance activities, 201 and 207.

This project was directed toward routine maintenance productivity. Productivity was measured in terms of cost per production unit. Consequently, this indicator only reflects the efficiency of conducting an activity. The other dimensions of work performance is effectiveness represented by the quality of maintenance work performed. It should be noted that productivity factor considered in

this study does not reflect the effectiveness aspect. A subdistrict may be efficient in terms of productivity factors, but may not be effective in performing routine maintenance activities.

As the major objective of a maintenance program is to preserve the highway condition, an indicator is needed to measure the quality or effectiveness of a program. Although efforts were made in the present study to identify the impact of various materials, equipment and work practices on routine maintenance effectiveness along with productivity considerations, a precise measurement of the effectiveness factor could not be accomplished in the absence of a clear definition of the quality of a given routine maintenance activity. It is recommended that a careful study of this aspect of maintenance performance be undertaken, because without a direct measure of quality, much of the MIS exercises would be in vain.

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APPENDIX 1

STATISTICAL ANALYSIS OF ROUTINE MAINTENANCE ACTIVITIES

A.1 Introduction

Regression analysis has been used widely in determining statistical relationships, yet there has been little use of the analysis of variance (ANOVA) or analysis of covariance (ANCOV) in this manner by engineers. Analysis of variance and analysis of covariance of both quantitative and qualitative data can provide much information about the parameters being studied [5].

A recent paper dealt with the use of ANOVA and ANCOV for determining influential observations and how they alter conclusions of tests of hypotheses in the ANOVA [6]. This paper offered an introduction into the use of ANOVA and ANCOV as well as computer packages available for use in analyzing data. This chapter presents the statistical analysis of crack sealing and shallow patching data using the Statistical Analysis System (SAS) computer package [7].

Phase II of the research program deals with the determination of the factors that influence routine maintenance productivity of crack sealing and shallow patching. These two activities were singled out because they are the highest cost routine maintenance activities performed by the IDOH [4]. A statistical analysis of the data produced by the MIS program was performed to determine which factors influence productivity of these two activities. Some of the following tests were run to ascertain whether the data being analyzed met the assumptions of the analysis of variance model (ANOVA). The assumptions of the ANOVA model are:

A. The dependent variable is random in nature.

B. Homogeneity of variance of independent variables exists.

C. Additivity of the data exists.

D. Normality of the data exists.

The following steps were used to analyze crack sealing and shallow patching data:

1. The two factor interaction of subdistricts by time was tested using the Tukey one degree of freedom for nonadditivity to determine whether or not an interaction of subdistricts and time exist.

2. Normality testing of the data was performed to determine whether or not the data conforms to one of the assumptions of the ANOVA model.

3. Analysis of covariance including the significant effects of the analysis of variance and the covariates was analyzed.

4. The covariates were tested for linearity to determine if unit cost changes linearly with changes in the covariates.

5. Homogeneity of slopes for the independent variables was investigated to determine whether or not the independent variables behave consistently over all subdistricts.

6. Correlation analysis of the covariates was run to determine if the variables being analyzed are independent of one another.

7. The model that best describes the variation of the data was determined.

8. The residuals from the "best" model were tested for normality to determine if they conform to the assumptions of the ANOVA model.

9. Comparing the subdistrict mean distribution of the unit cost for the unadjusted (raw) means and the

subdistrict mean distribution of the unit cost after the means have been adjusted for the variables that affect the unit cost. Adjusting the means refers to removing the influence of a variable from the dependent variable by use of a least squares procedure [5].

The subdistricts were numbered so that the following analysis could be performed. Table A.2.0 shows the numbering of the subdistricts and Figure A.2.0 shows the location of each subdistrict within the state of Indiana.

A.2 Statistical Analysis of Crack Sealing Data

This section presents a statistical method for analyzing routine maintenance productivity of crack sealing data for the state of Indiana for the 1982-83 fiscal year. The analysis performed on the dependent variable, unit cost of crack sealing per lane mile of road sealed (cost/lane mile sealed), over two month periods from July 1982 through June 1983 for each of the thirty seven subdistricts in Indiana, is presented in this paper. The following ten covariates were measured simultaneously with the dependent variable (over each two month period).

X1. Frequency of sealing by a subdistrict (how often crack sealing was performed in the two month period).

X2. Average accomplishment per day or lane miles

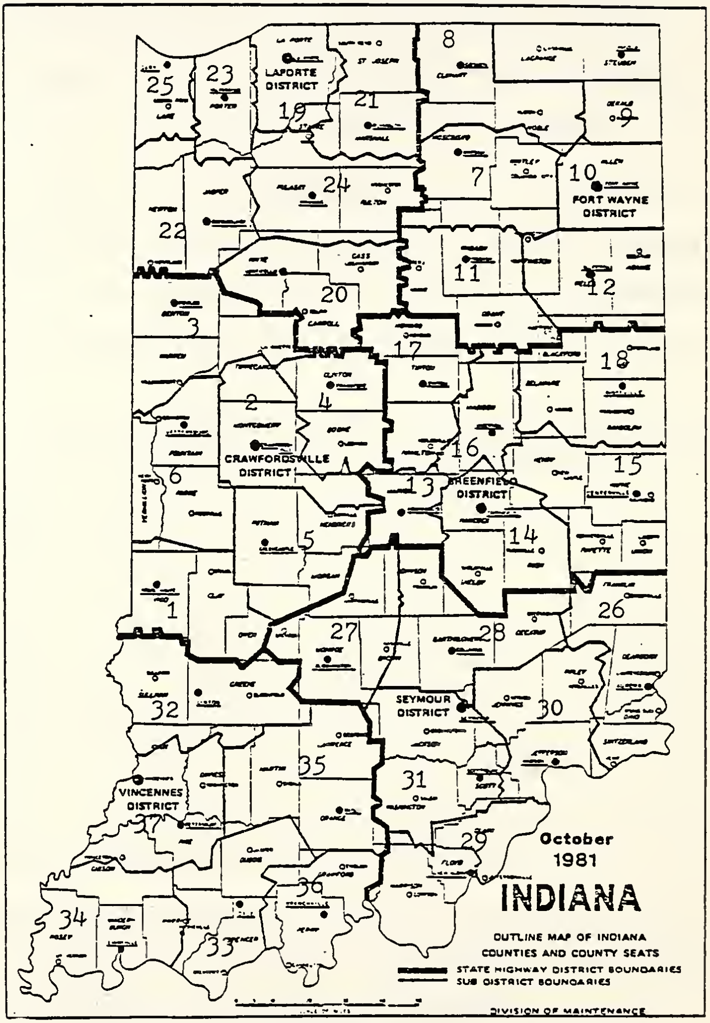

Figure A.2.0 Location of Subdistricts within Indiana

Table A.2.0 Subdistrict Numbering Used for Statistical Analysis.

Subdistricts	Number
Terre Haute	1
Crawfordsville	2
Fowler	3
Frankfort	4
Greencastle	5
Veedersburg	6
Warsaw	7
Goshen	8
Fort Wayne	9
Angola	10
Wabash	11
Bluffton	12
Indianapolis	13
Greenfield	14
Centerville	15
Anderson	16
Tipton	17
Ridgeville	18
Laporte	19
Monticello	20
Plymouth	21
Rensselar	22
Valparaiso	23
Winamac	24
Gary	25
Aurora	26
Bloomington	27
Columbus	28
New Albany	29
Madison	30
Seymour	31
Linton	32
Dale	33
Evansville	34
Paoli	35
Branchville	36
Petersburg	37

sealed per day of crack sealing.

X3. Average crew size per day (average number of crew members used per day for the two month period).

X4. Average hours worked per accomplishment

X5. FSM - Bituminous material 4431 Asphalt

X6. PSM - Bituminous material 4431 Asphalt

X7. FSM - Backfill material 4251

X8. PSM - Backfill material 4251

X9. FSM - Seal/Cover aggregate material 4252

X10. PSM - Seal/Cover aggregate material 4252

where, FSM = fraction of the time the material was used (during a two month period)

PSM = average amount of the material used per accomplishment

A.2.1 Factor Interaction

An analysis of variance (ANOVA) was run on the data to determine if an interaction between the variables, subdistrict and time (2 month periods), existed. This running of this test was necessary to examine if the data conformed to the basic assumptions of the ANOVA model given in Section A.1 of this chapter. Since there was only one observation per cell (only one mean for each subdistrict at a specific time period), the Tukey one degree of freedom for nonadditivity procedure [9] was used

to test for variable interaction. The results of the analysis are given in Table A.2.1. Appendix 2 lists a program used to run the Tukey test on SAS. The interaction between subdistricts and time was found to be non-significant, with PR > F of 0.50 (where PR stands for probability). The PR > F value is the calculated α-level value, or the probability of rejecting the hypothesis that there is no interaction when there is. In this case, the interaction term would be significant if its calculated F value was tested by a F-critical using an α-level of 0.50. It is a common practice to use an α-level of 0.05 when testing for significance of terms in a statistical analysis. Therefore, a PR > F value of 0.05 would indicate that the term being tested is significant when tested by an F-critical obtained using an α-level equal to 0.05. Since there was no interaction between the variables subdistrict and time, the interaction term was considered to have no significant variation, and thus were removed from the model. With no interaction between subdistricts and time present, one can conclude that the unit production of crack sealing among subdistricts does not change with time periods. Since there was no interaction present, normality and homogeneity testing of the raw data were performed.

A.2.2 Normality of Raw Data

Normality testing of the data was performed to

Table A.2.1 Results of Tukey One Degree of Freedom for Nonadditivity Testing.

Source	Type III SS	df	F-value	PR>
S	308603.593	17	1.54	0.11
M	19796.895	3	0.56	0.64
S*M	5436.604	1	0.46	0.50

Class: M (time) 1,2,5,6
S (subdistrict) 2,3,4,6,10,12,13,16,17,18
19,20,21,22,24,29,32,37

determine if the data conforms to the basic assumptions of the ANOVA model, in this case, whether or not the data is normally distributed. If it is not, the the data may be changed by the use of a transformation so that it is normally distributed. Transformation of the data simply means changing the data by using a function (squaring the data or taking the log of the data) before the analysis of variance or covariance is performed. A normality test was performed on the dependent variable unit cost from a data set that excluded time period three and four. Time period three (May-June 1983) was excluded because only seven of the thirty seven subdistricts reported that they performed crack sealing during this time period. Also those subdistricts that did perform crack sealing during this time period did so sparingly. Therefore, mean values of the variables being analyzed were obtained from only a few work sections and do not accurately reflect two months of crack sealing work. Time period four (July-August 1982) was excluded because there were no recordings of crack sealing being performed by any subdistrict for this time period. It was felt that excluding these two time periods from the analysis was justified due to the fact that differences among subdistricts cannot exist if no work is performed. The normality test was then run on the residuals produced by the regression model:

$$Y_i = \beta_0 + \beta_1 X1_i + \ldots + \beta_{46} X46_i + \varepsilon_i \qquad (A.2.1)$$

where:

$i=1,\ldots,37$

β_{0-46} = parameters

Y_i = Unit production for subdistrict i

$X1_i$ = Frequency of application

$X2_i$ = Average accomplishment

$X3_i$ = Average crew size

$X4_i$ = Average hours worked per accomplishment

$X5_i$ = FMS - Bituminous material 4431

$X6_i$ = PMS - Bituminous material 4431

$X7_i$ = FMS - Backfill material 4251

$X8_i$ = PMS - Backfill material 4251

$X9_i$ = FMS - Seal/Cover aggregate material 4252

$X10_i$ = PMS - Seal/Cover aggregate material 4252

$X11_i$ - $X46_i$ = dummy or indicator variables

ε_i = error term; independent $N(0,\sigma^2)$

A D-statistic value of 0.0803765 was calculated using SAS [7]. D-critical was then calculated at the 0.01 and 0.05 α-levels and their values are 0.134 and 0.11, respectively. Since the D-statistic is less than D critical, normality of the data was assumed. This is also shown by the normality plot given in Figure A.2.1.

A.2.3 Homogeneity of Variance

One of the basic assumptions in ANOVA and ANCOV is

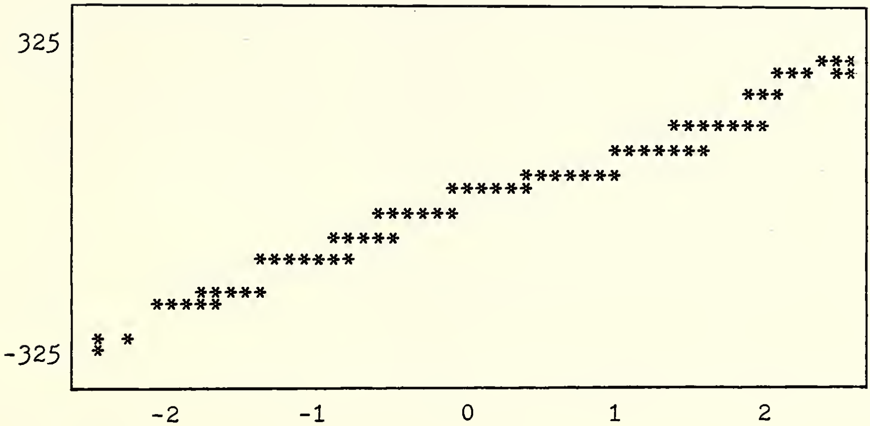

Figure A.2.1 Normality Plot of Residuals obtained from Equation A.2.1.

that the data have equal variance among factors. In the case of crack sealing data, the variance among subdistricts must be homogeneous for the experimenter to draw any conclusions from the analysis.

The Burr-Foster Q-test of homogeneity [9] was performed on the crack sealing data. Table A.2.2 lists the variance and degrees of freedom (DF) for each subdistrict. Since unequal sample sizes were present, the calculated "q" (calculated statistical value) was done by the use of the formula:

$$q = \bar{v}\left(\left[\sum_{i=1}^{i=37} v_i s_i^{4}\right] / \left[\sum_{i=1}^{i=37} v_i s_i^{2}\right]^{2}\right) \qquad (A.2.2)$$

where: $i = 1,\ldots,37$

$\bar{v}$ = mean degrees of freedom for all subdistricts

v_i = degrees of freedom for subdistrict i

s_i^4 = squared variance of subdistrict i

s_i^2 = variance of subdistrict i

This "q" value was then compared to the "q" percentile points for Q-tests. This comparison was used to judge whether the independent variables in question indeed have homogeneity of variance. In this case, "q" calculated was 1.7797×10^{-8}. The "q" percentile point was found to be approximately 0.062 at the α-level of 0.01, p equal to 37, and $\bar{v}$ equal to 2.738. Since "q" calculated is less than

Table A.2.2 Subdistrict Variance used for Homogeneity of Variance Testing.

Subdistrict	Variance	Degree of Freedom
1	44.274	1
2	1005.973	3
3	36101.887	3
4	62155.296	3
5	36244.752	2
6	14183.759	3
7	5654.470	2
8	836.701	2
9	1492.236	2
10	23650.548	3
11	1132.119	2
12	1062.593	3
13	4041.611	3
14	3833.878	2
15	6525.054	2
16	8715.287	3
17	2677.183	3
18	4972.566	3
19	12219.488	3
20	18685.979	3
21	65.829	3
22	4976.207	3
23	502.540	1
24	5377.574	3
25	552.316	1
26	5325.207	2
27	40.195	1
28	244.218	2
29	2131.350	3
30	222.373	2
31	902.863	2
32	1687.950	3
33	439.303	2
34	2364.189	2
35	536.768	2
36	1558.513	2
37	1092.190	3

Sum of s^4 = 2.273x10
Sum of s^2 = 750228
Mean DF = 2.738

"q" critical, homogeneity of variance was assumed for the crack sealing data and the data can now be analyzed using an analysis of covariance procedure.

A.2.4 Analysis of Covariance

An analysis of covariance was run with all the covariates, X1,. . .,X10, using the SAS General Linear Model (GLM) procedure [7] on the model:

$$Y_{ij} = \mu + S_i + M_j + \beta_1 X1_{ij} + \ldots + \beta_{10} X10_{ij} + \varepsilon_{(ij)} \qquad (A.2.3)$$

where:

$i = 1,\ldots,37 \quad j = 1,\ldots,6$

μ = overall mean

S_i = the ith subdistrict

M_j = the jth time period

β = coefficients of the X variables

$X1_{ij}$-$X10_{ij}$ = the same as in equation (A.2.1)

$\varepsilon_{(ij)}$ = error term

An analysis of covariance (ANCOV) was used with this data, because it allows the addition of quantitative (measured) variables in the analysis of the factor (qualitative) variables. Type III sum of squares was used to determine whether or not a particular covariate should remain in the model. Type III sums of squares are preferred in analyzing data because the variation of the dependent

variable (unit cost) explained by an independent variable is calculated as if all other independent variables have been accounted for. Therefore, if a specific variable truly affects unit cost, it will be shown having a large Type III sums of squares and a small PR>F value. From the analysis (Table A.2.3), covariates X1, X2, X3, and X8 could be removed from the model, along with the time factor M. Any covariate that had a PR > F greater than 0.10 was eliminated from the model as not significantly affecting the dependent variable. Specifically, when the variance of the particular independent variable is approximately zero, it was dropped from the model. The model is now of the form:

$$Y_{ij} = \mu + S_i + \beta_4 X4_{ij} + \beta_5 X5_{ij} + \beta_7 X7_{ij} + \beta_9 X9_{ij} + \beta_{10} X10_{ij} + \varepsilon_{ij} \qquad \text{(A.2.4)}$$

A.2.5 <u>Analysis of Covariance of Reduced Model</u>

An analysis of covariance was performed on the model given in Equation A.2.4 using the GLM procedure. Again the Type III sum of squares was used to determine whether or not particular covariates should remain in the model. Table A.2.4 shows that all the covariates used in the model are significant on unit cost (Y), and they should be left in the model. The variable subdistrict (S), having a PR > 0.03 should also remain in the model. That is, there

Table A.2.3 Analysis of Variance Table for Equation A.2.3.

Source	Type III SS	df	F-value	PR>
S	8.937	36	1.40	0.10
M	0.227	3	0.43	0.73 *
X1	0.249	1	1.41	0.23 *
X2	0.010	1	0.06	0.81 *
X3	0.003	1	0.02	0.89 *
X4	46042.758	1	99999.99	0.00
X5	21.847	1	123.43	0.00
X6	123360.203	1	99999.99	0.00
X7	1.243	1	7.02	0.00
X8	0.224	1	1.26	0.26 *
X9	0.646	1	3.65	0.05
X10	1468.490	1	8296.43	0.00

Mean Square = 0.177
R-Square = 0.999990
Y Mean = 277.971

Note: * variables were taken out of the model at this stage.

Table A.2.4 Analysis of Variance Table for Equation A.2.4.

Source	Type III SS	df	F-value	PR>
S	9.928	36	1.64	0.03
X4	123835.287	1	99999.99	0.00
X5	23.546	1	140.34	0.00
X6	143434.264	1	99999.99	0.00
X7	1.917	1	11.42	0.00
X9	0.970	1	5.78	0.01
X10	1832.672	1	10922.69	0.00

Mean Square = 0.1679
R-Squared = 0.999990
Y Mean = 277.971

Note: No elimination of variables by F-value at alpha = 0.05 level.

is a difference of unit cost among the subdistricts when analyzing the variables found in Equation A.2.4. It should be noted that Type III sum of squares has increased from the original model found in Equation A.2.3 (see Table A.2.3 and Table A.2.4) for subdistricts (S) when the expected result was that the sum of squares should remain the same or decrease (because fewer variables were in the model).

The residuals obtained from model (Equation A.2.4), shown in Figure A.2.2, were plotted to see if their distribution was normal. A normality plot was also produced (see Figure A.2.3) to aid in the determination whether the distribution was normal. If the residuals are normal, then the residual plot should appear roughly as a horizontal band about the 0.0 point. The residuals seem to form a horizontal band, with 54 residuals between the mean and plus one standard deviation and 52 residuals between the mean and minus one standard deviation. From the shape of the plot and the fact that the data are normal in distribution, homogeneity of variance of the dependent variable is assumed. It is important to note here that there were also four means that were outside the two standard deviation limits but they were within three standard deviations from the mean. They produced no problems in this analysis. If mean values much greater than two standard deviations limits, the results of the

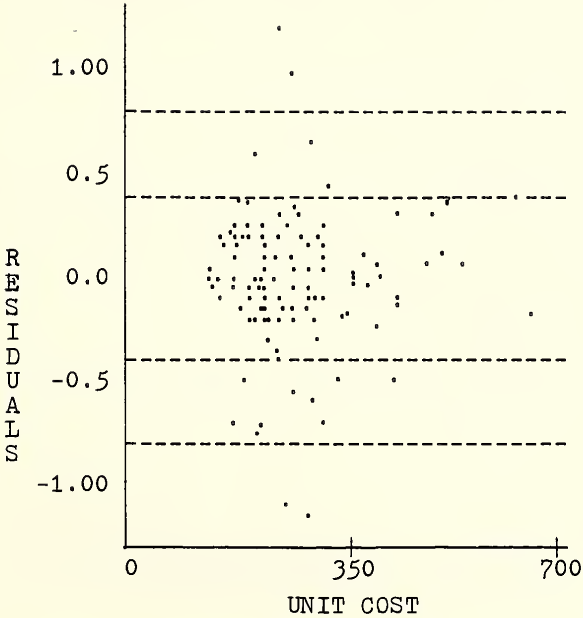

Figure A.2.2 Plot of Residuals obtained from Equation A.2.4.

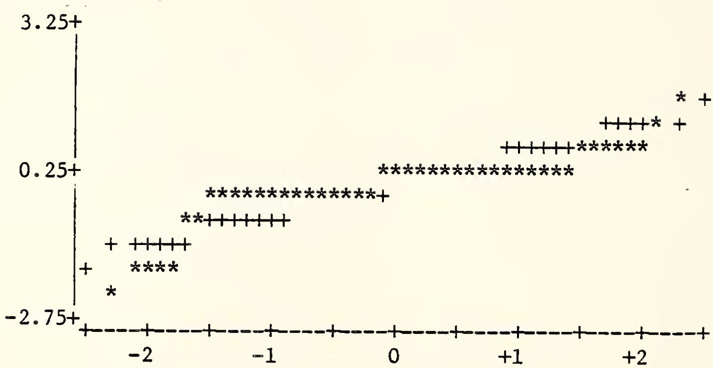

Figure A.2.3 Normality Plot of the Residuals obtained from Equation A.2.4.

testing may not accurately reflect how the data truly acts.

A.2.6 Linearity of Covariates

For the remaining covariates, X4, X5, X6, X7, X9, and X10, there was a need to ascertain whether or not they meet the assumptions of the model. In other words, it was necessary to determine if they were independent and linear in form.

To test whether the variables are linear in form, each variable (X1, . . . , X10) was plotted against the dependent variable Y, shown in Figures A.2.4 through A.2.13. It can be seen that X4, X6, and X10 are the only variables that are linear in form. The plots of Y versus X5, X7, X8, and X9 show linear form, yet most of the points in the graphs are either zero or one, resulting in a vertical line. These variables should therefore be eliminated from the model, since they do not reflect a change in X with a change in Y. The model is now of the form:

$$Y_{ij} = \mu + S_i + \beta_4 X4_{ij} + \beta_6 X6_{ij} + \beta_{10} X10_{ij} + \varepsilon_{(ij)} \qquad (A.2.5)$$

The remaining covariates, X4, X6 and X10, must be independent of each other (do not affect each other significantly) to conform to the assumptions of the

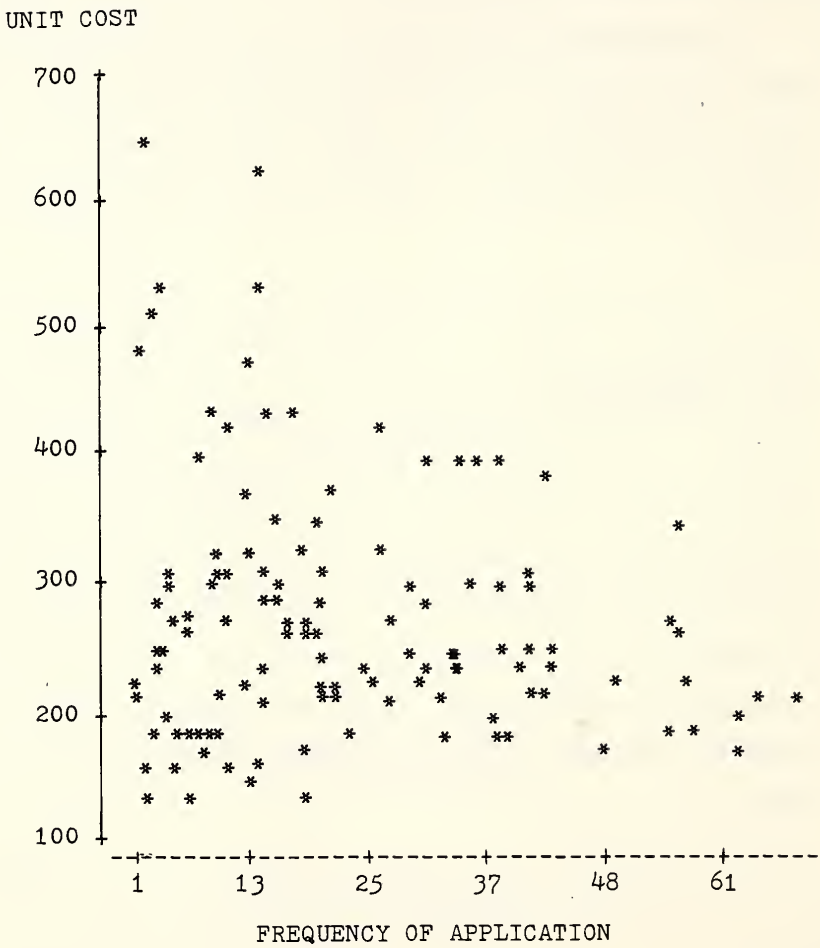

Figure A.2.4 Plot of Unit Cost vs. Frequency of Application (X1).

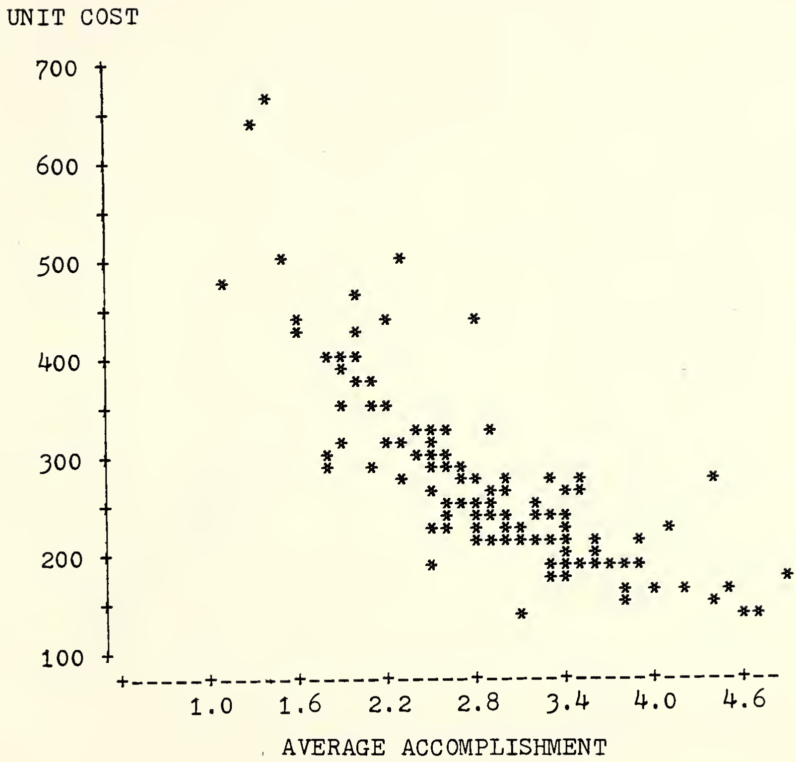

Figure A.2.5 Plot of Unit Cost vs. Average Accomplishment (X2).

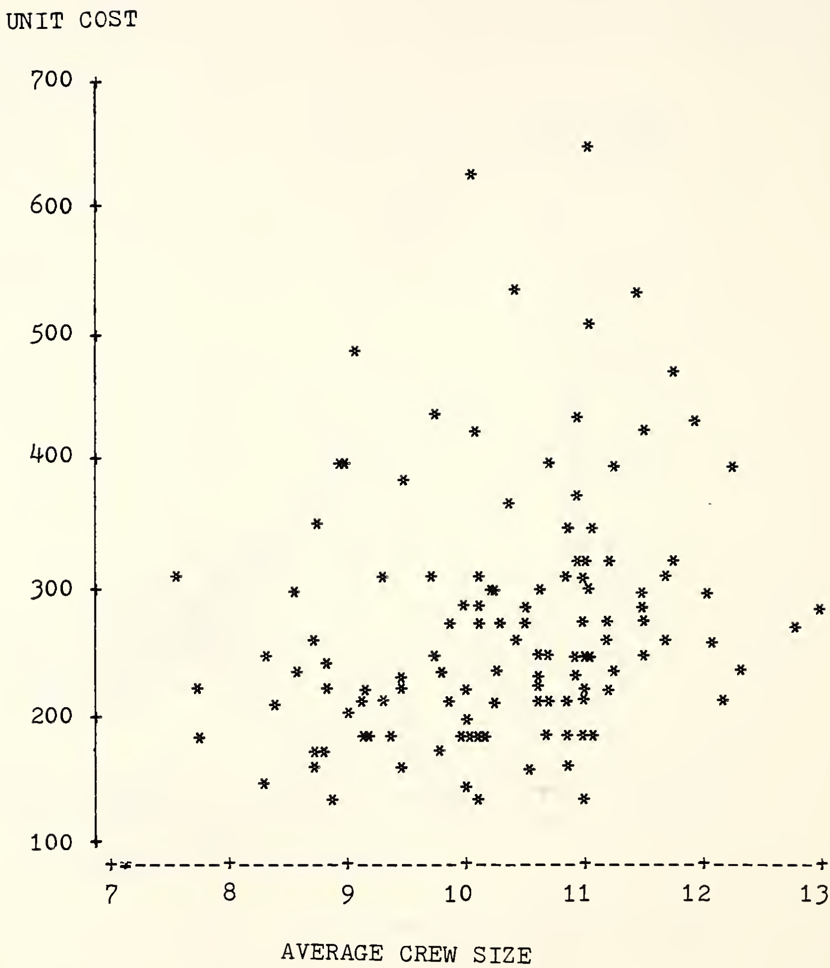

Figure A.2.6 Plot of Unit Cost vs. Average Crew Size (X3).

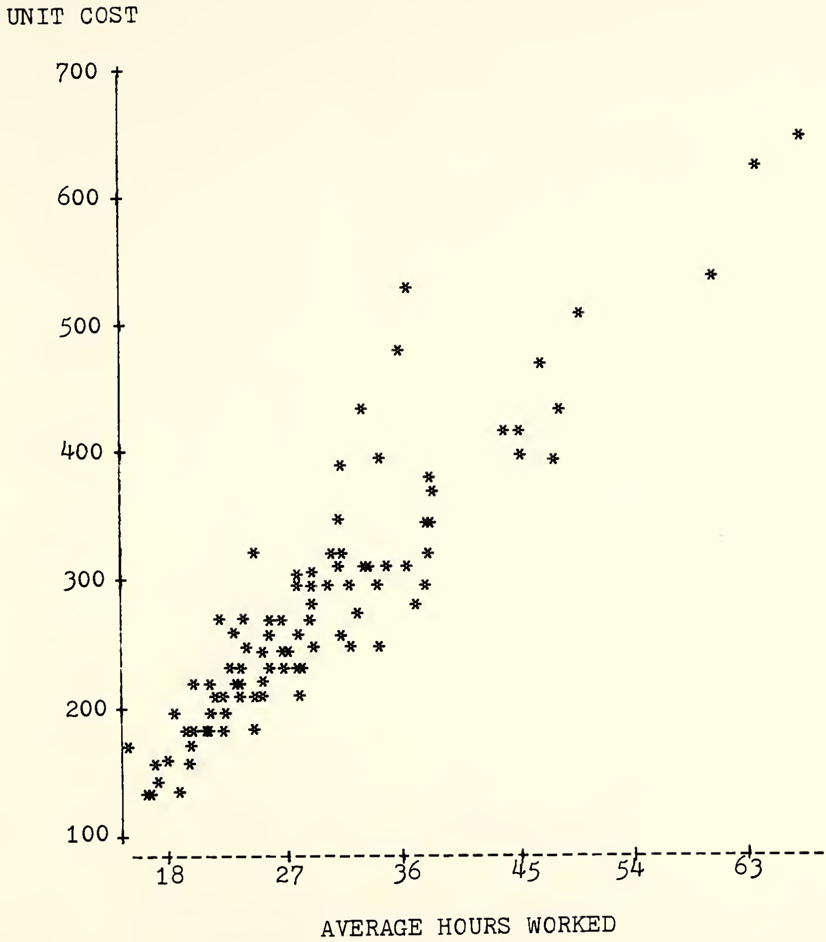

Figure A.2.7 Plot of Unit Cost vs. Average Hours Worked (X4).

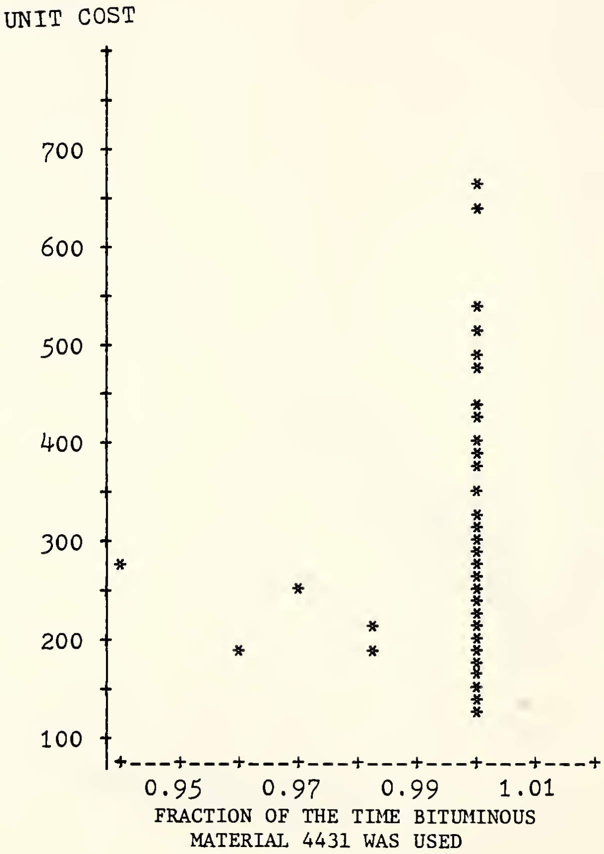

Figure A.2.8 Plot of Unit Cost vs. Fraction of the Time Bituminous Material 4431 was used (X5).

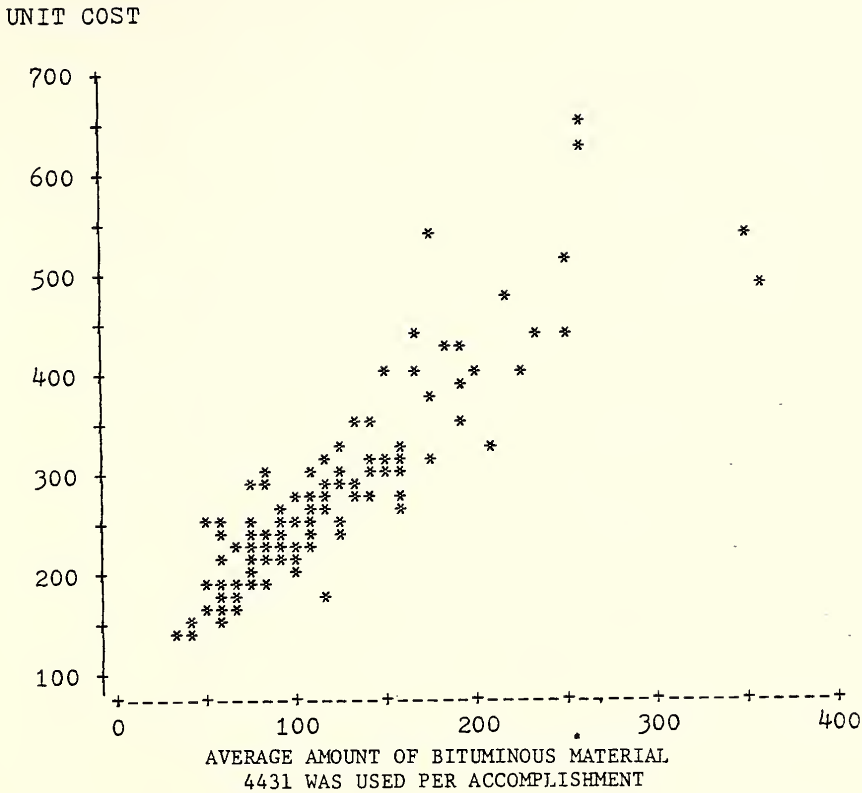

Figure A.2.9 Plot of Unit Cost vs. Average Amount of Bituminous Material 4431 used per Accomplishment (X6).

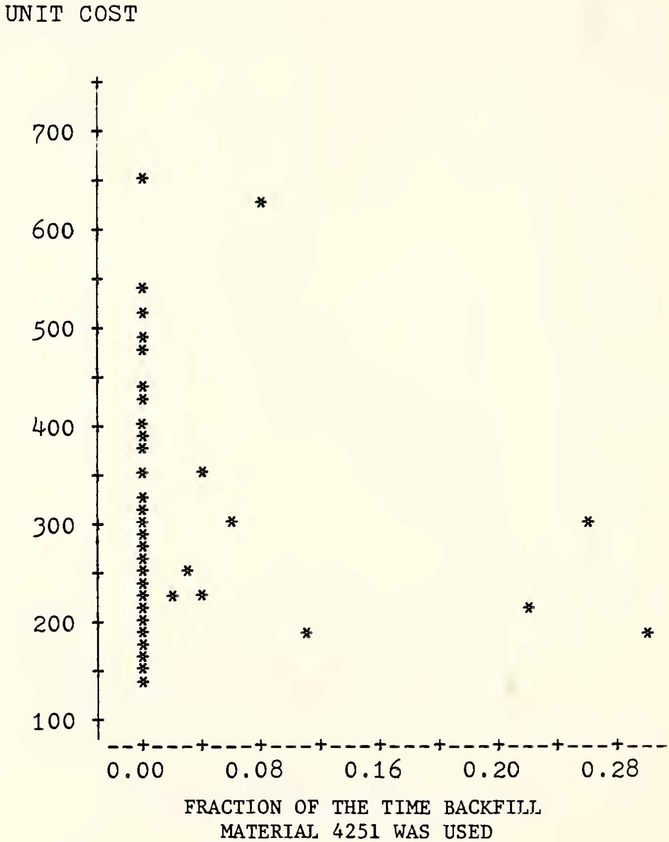

Figure A.2.10 Plot of Unit Cost vs. Fraction of the Time Backfill Material 4251 was Used (X7).

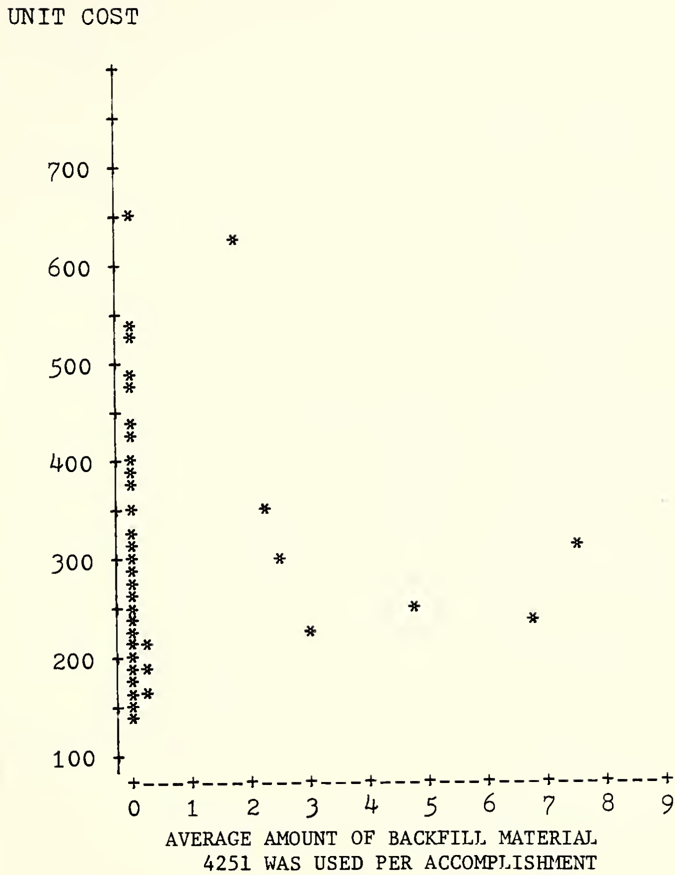

Figure A.2.11 Plot of Unit Cost vs. Average Amount of Backfill Material 4251 used per Accomplishment (X8).

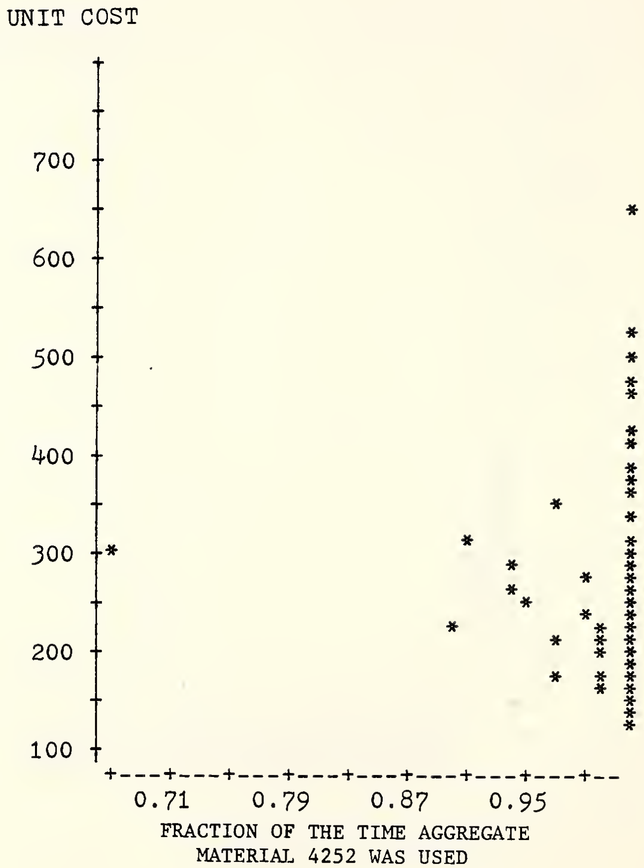

Figure A.2.12 Plot of Unit Cost vs. Fraction of the Time Aggregate Material 4252 was Used (X9).

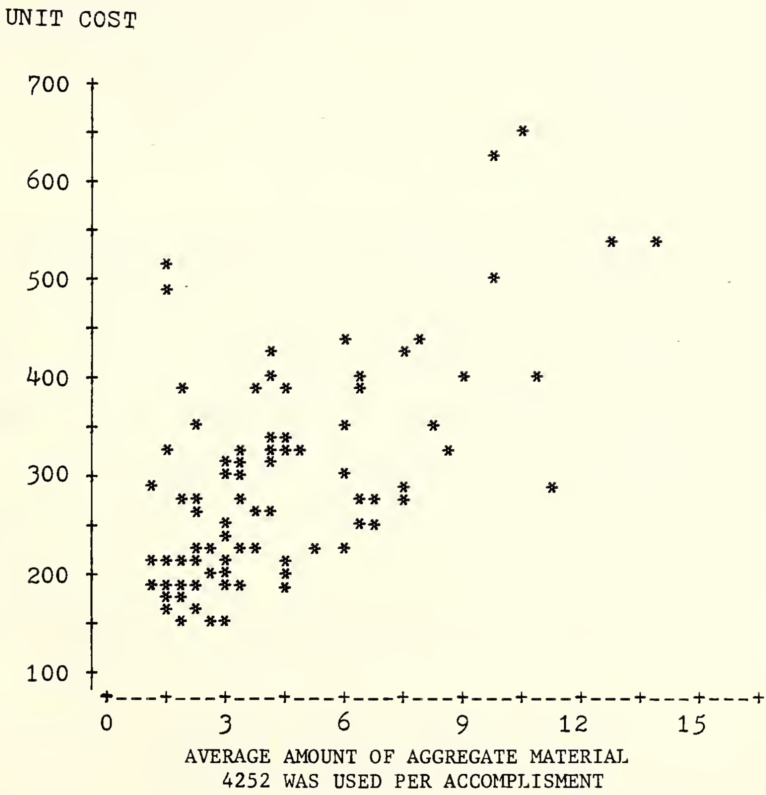

Figure A.2.13 Plot of Unit Cost vs. Average Amount of Aggregate Material 4252 used per Accomplishment (10).

ANOVA model. To test independence of X4, X6, and X10, a correlation matrix was produced, and the variables involved were compared. The matrix is displayed in Figure A.2.14. From Figure A.2.14, the correlation between X4 and X6 is 0.602, the correlation between X4 and X10 is 0.455, and the correlation between X6 and X10 is 0.491. All these values are relatively low, therefore independence of the variables was assumed.

A.2.7 Analysis of Covariance of Further Reduced Model

From the previous testing, the model has been reduced to the form given in Equation A.2.5. An analysis of covariance was run on the model given in Equation A.2.5 using the SAS GLM procedure. The results from that analysis are given in Table A.2.5. The analysis showed that the three covariates X4, X6, and X10, should remain in the model, yet the variable, subdistrict, came out as non-significant with a PR > 0.19.

The residual plot against Y gives a horizontal band around the mean, with five values within three standard deviations of the mean. This plot is shown in Figure A.2.15. The residuals were graphed against X4, X6, and X10, all giving a plot similar to the one shown in Figure A.2.15.

	X4	X6	X10
X4	1.000	0.602	0.4551
X6	0.602	1.000	0.491
X10	0.4551	0.491	1.000

Figure A.2.14 Correlation Matrix of the Variables X4, X6 and X10.

Table A.2.5 Analysis of Variance Table for Equation A.2.5.

Source	Type III SS	DF	F Value	PR >
S	26.120	36	1.25	0.19
X4	126318.744	1	99999.99	0.00
X6	143449.888	1	99999.99	0.00
X10	1819.117	1	3140.92	0.00

Mean Square 0.579
R Squared 0.999965
Y Mean 277.971

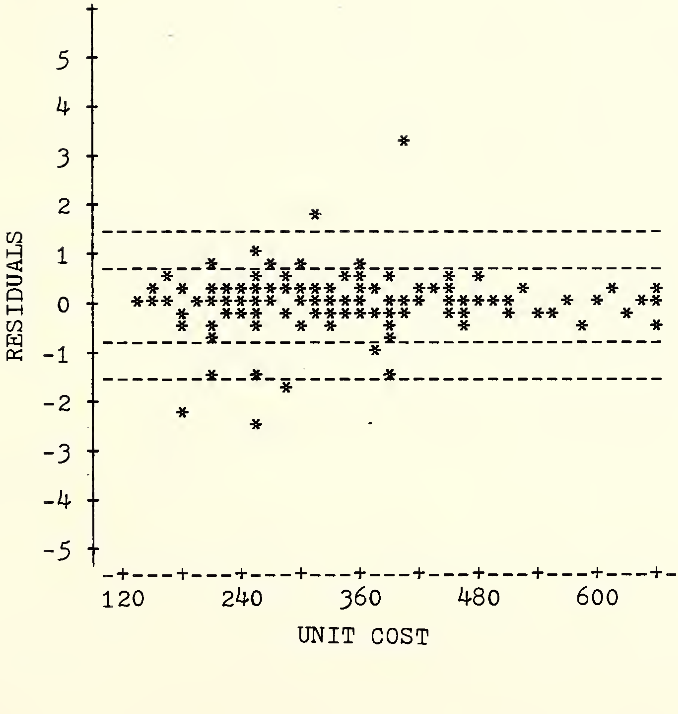

Figure A.2.15 Plot of the Residuals obtained from Equation A.2.5.

Due to the fact that the variable, subdistrict, was found to be non-significant, a linear regression model was run using the model:

$$Y_{ij} = \mu + \beta_0 + \beta_4 X4_{ij} + \beta_6 X6_{ij} + \beta_{10} X10_{ij} + \varepsilon_{(ij)} \quad (A.2.6)$$

The results of this analysis are found in Table A.2.6. The residual plot against Y, shown in Figure A.2.16, reveals a narrower horizontal band than Figure A.2.15. There were five residuals present as before, yet they are farther away from the mean, some over four standard deviations. Before the factor "subdistricts" was removed from the model, further testing of both models A.2.5 and A.2.6 was performed and is presented in the following sections.

A.2.8 <u>Normality Testing on the Residuals</u>

The residuals obtained from the model given in Equation A.2.6 must be independent and normally distributed to satisfy the assumption of the ANOVA and ANCOV models. Therefore, a test on normality of the residuals, adjusted for the variables X4, X6, and X10 was performed.

The test used to test for normality of the residuals was the Kolmogorov-Smirnov test [10] for N > 50. Since there were thirty nine parameters to estimate and the

Table A.2.6 Analysis of Variance Table for Equation A.2.6.

Source	Type III SS	DF	F Value	PR >
X4	224592.049	1	99999.99	0.00
X6	243638.061	1	99999.99	0.00
X10	6254.382	1	10043.63	0.00

Mean Square 0.623
R Squared 0.999946
Y Mean 277.971

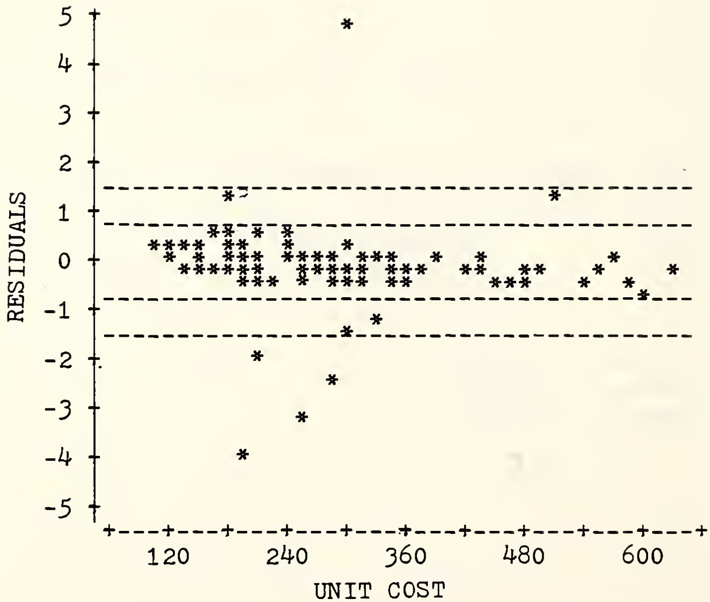

Figure A.2.16 Plot of the Residuals obtained from Equation A.2.6.

number of cases was 125, there were eighty six degrees of freedom for the residuals. The Kolmogorov-Smirnov D-statistic was 0.1895. The D-critical was calculated by:

$$\text{for } \alpha = 0.01 \quad D_{crit} = 1.63/(n)^{1/2}$$
$$\alpha = 0.05 \quad D_{crit} = 1.36/(n)^{1/2}$$

The value of "n" used was eighty six (degrees of freedom) which gave the D-critical values: $D_{0.01} = 0.176$, $D_{0.05} = 0.146$. Since the D-statistic observed was 0.1895 (greater than 0.176 and 0.146) the assumption of normality of the residuals was rejected.

A frequency plot of the residuals was made to aid in finding the reason the residuals were not normally distributed. From the residual versus frequency plot (Figure A.2.17) it was judged that the symmetry of the distribution was good, but two points tend to cause the distribution to not be normal. A normality plot was also produced to show the distribution of the residuals. These points showed an inconsistency in the unit costs versus the independent variables. Unit cost was low while labor and material costs were high or vice versa. This leads one to believe that the data were incorrectly recorded on either the crew day card or the data tape.

To determine whether this departure from normality warranted a transformation of the data, the distribution of the raw data was looked at more closely. The

```
           3.25 +*                          1
                .
                .
                .*                          1
      R         .*                          1
      E         .****                       7
      S    0.25 +**************************  51
      I         .**************************  52
      D         .***                        5
      U         .*                          1
      A         .**                         4
      L         .*                          1
      S   -2.75 +*                          1
                 ----+----+----+----+----+-

                       FREQUENCY
```

Figure A.2.17 Plot of Residuals vs. Frequency.

Kolmogorov-Smirnov test for normality was given in section A.2.2. The distribution of the residuals for the unadjusted model Y = S was given earlier as 0.0804 and an approximate $D_{0.05}$ critical was 0.11. Also another test for normality that was run on the data was the Shapiro-Wilk's test. Thwas test is run on the dependent variable values for each subdistrict. The test does require that there be at least three observations for each subdistrict. Both the Kolmogorov-Smirnov and the Shapiro-Wilk's test are a mathematical means of determining whether or not the data set is approximately normal in distribution. Table A.2.7 has the results of the Shapiro-Wilk's test. From the Shapiro-Wilk's test, it was found that all but subdistricts 5 and 7 were normally distributed (subdistricts 1, 23, 25, and 27 were not estimable due to having sample sizes less than 3). From the Kolmogorov-Smirnov and the Shapiro-Wilk testing on the unadjusted model Y = S, the distribution of the data can be assumed normal and a transformation of the data was not performed. There was no previous reason or theory for the data to act non-linear in form. The two data points that caused such large residuals were not removed from the data because they are the mean value for unit cost and all information on a subdistrict for a specific time period would be lost if they were removed from the data set.

A.2.9 Homogeneity of Slopes

The homogeneity of slopes for the independent

Table A.2.7 Results of the Shapiro-Wilk Normality Testing.

Subdistrict Number	Shapiro-Wilk W (calculated)	Percentage Point = 0.01	Sample Size
1	NE	NE	2
2	0.8788	0.687	4
3	0.9028	0.687	4
4	0.9525	0.687	4
5	0.7528	0.753	3
6	0.9579	0.687	4
7	0.9722	0.753	3
8	0.9074	0.753	3
9	0.7768	0.753	3
10	0.8938	0.687	4
11	0.8554	0.753	3
12	0.8938	0.687	4
13	0.8924	0.687	4
14	0.9963	0.753	3
15	0.9677	0.753	3
16	0.8272	0.687	4
17	0.8962	0.687	4
18	0.8581	0.687	4
19	0.9395	0.687	4
20	0.9909	0.687	4
21	0.9425	0.687	4
22	0.9644	0.687	4
23	NE	NE	2
24	0.8138	0.687	4
25	NE	NE	2
26	0.9998	0.753	3
27	NE	NE	2
28	0.8461	0.753	3
29	0.9527	0.687	4
30	0.7771	0.753	3
31	0.9532	0.753	3
32	0.9622	0.687	4
33	0.9902	0.753	3
34	0.9581	0.753	3
35	0.8871	0.753	3
36	0.9996	0.753	3
37	0.6803	0.687	4

NE = Not estimable, sample size too small.

variables were tested using the model given in Equation A.2.5. This test is used to determine whether or not the slope of the β coefficient for each of the subdistricts (1 through 37) are equal. If the β coefficients for each variable are approximately equal for all subdistricts, then they have homogeneous slopes and remain in the model. If the coefficients have unequal slopes, then the variable should be removed from the model because it does not follow the additive law of the ANOVA model. The results of these tests are given in Table A.2.8. The testing showed that there is no interaction between S and X4, S and X6, or S and X10, therefore the β's can be assumed constant. Since homogeneity of the slopes was ascertained for the covariates X4, X6, and X10, these covariates should remain in the model. A decision concerning whether or not subdistricts are significantly different can be reached by comparing the least square adjusted means, for unit cost of crack sealing in fiscal year 1983, obtained from the following models given in Equation A.2.5 and A.2.6. If the variation of the adjusted means associated with each model is small then the variable, subdistricts, should be removed from the model because it does not affect the variation of unit cost.

A.2.10 Least Squares Adjustment of Means

A comparison was needed between the original data

Table A.2.8 Results of the Homogeneity of Slope Testing.

Source	Type III SS	df	F-value	PR>
S	28690.009	36	0.34	0.99
X4	17353.638	1	7.39	0.00
S*X4	44056.016	1	0.52	0.97
S	31060.183	36	0.50	0.98
X6	10210.850	1	5.85	0.01
S*X6	61371.259	36	0.98	0.51
S	210111.532	36	0.93	0.58
X10	13200.555	1	2.10	0.15
S*X10	187414.650	36	0.83	0.72

means and the adjusted means for the model that included subdistricts (Equation A.2.5) in order to determine how well the model accounts for the variation in unit cost. Also, a comparison of the original data means and the adjusted means for the model without subdistricts (Equation A.2.6) was performed to determine how well the model accounts for the variation in unit cost. The means for the original data and the adjusted means of Equation A.2.5. were obtained by using the SAS GLM procedure [7], and a program was written in SAS language to obtain the adjusted means for the model given in Equation A.2.6 . The adjusted means for Equation A.2.6 were calculated using the formula:

$$\bar{Y}_{i\ adj} = \bar{Y}_i - b_4(\bar{x}_{i4}-\bar{x}_4) - b_6(\bar{x}_{i6}-\bar{x}_6) - b_{10}(\bar{x}_{i10}-\bar{x}_{10})$$

where $i = 1, 2, \ldots, 37.$

b_4 = coefficient for X4

b_6 = coefficient for X6

b_{10} = coefficient for X10

Appendix 3 lists a program which was used for this purpose. Before the adjusted means for model (A.2.6) could be obtained, the coefficients of independent variables had to be obtained. The coefficients were obtained by running a stepwise regression (PROC STEPWISE procedure) [7] and are given in Table A.2.9. Adjusting

Table A.2.9 Regression Coeficients for the Variables Found in Equation A.2.7.

Source	Beta-value	Std. Error	C(P)
Intercept	-0.35177778		4.000
X4	5.82305987	0.00969618	
X6	0.77957546	0.00124633	
X10	2.99226478	0.02985758	

the subdistrict unit cost is to remove the influence of the independent variables from the mean unit cost for each subdistrict. This is a mathematical procedure for removing the variation of the unit cost explained by the independent variables contained in the model.

If the variance of the adjusted means is small, then the variables contained in the model explain the variation found in the unit cost (for the raw data) and the correct model has been used to analyze the data. However, if the variance of the adjusted means is large, then the wrong variables have been included in the model.

The least square means for both models were obtained. A Duncan pairwise comparison test [7] was run on the least square means and compared to the original means. The Duncan test allows the testing of all pairwise combinations of means to determine if they are statistically different. The results of this test are only approximate due to unequal cell size among subdistricts when calculating the mean unit cost of each subdistrict. These results are shown in Table A.2.10 which show there was very little difference in the adjusted means for the two models. Also, each model reduces the variation of the original means by a significant amount, showing that the covariates chosen to remain in the model do a good job of predicting the unit cost.

Table A.2.10 Comparison of Unadjusted and Adjusted Least Squares Means.

Original Data		Equation A.2.6		Equation A.2.5	
Sub.	Raw Means	Sub.	Adjusted Means	Sub.	Adjusted Means
5	410.65	15	279.60	15	279.54
19	398.61	5	278.48	5	278.48
3	384.01	30	278.44	30	278.42
4	382.01	33	278.37	33	278.40
20	379.88	36	278.29	23	278.30
10	370.67	23	278.28	36	278.29
6	360.05	37	278.19	20	278.28
18	344.79	20	278.17	18	278.22
7	335.58	32	278.15	37	278.20
11	330.85	18	278.15	32	278.19
15	313.32	1	278.11	31	278.14
26	296.62	31	278.11	1	278.13
24	289.02	9	278.11	9	278.09
25	288.77	13	278.09	2	278.05
8	288.10	21	278.08	21	278.05
16	285.22	2	278.07	4	278.03
22	275.58	7	278.03	25	278.03
27	270.70	11	278.03	13	278.03
17	269.78	12	278.02	22	278.03
2	269.58	26	278.01	24	278.02
13	264.65	4	278.01	12	278.02
29	260.90	3	278.01	3	278.01
14	250.49	24	278.01	7	278.01
21	247.81	22	277.01	11	277.99
1	246.55	25	277.99	26	277.97
32	221.50	27	277.92	27	277.91
23	205.53	35	277.90	35	277.91
35	204.34	10	277.90	10	277.87
12	194.79	34	277.85	34	277.82
34	194.53	6	277.81	6	277.80
37	194.39	8	277.71	19	277.75
28	192.44	19	277.64	8	277.72
33	189.46	28	277.62	28	277.59
9	188.51	17	277.54	17	277.52
36	183.65	16	277.30	16	277.24
30	174.29	29	277.15	29	277.10
31	163.94	14	276.33	14	276.31

Original Data	Equation A.2.6	Equation A.2.5
Mean 262.09	Mean 277.985	Mean 277.985
Std. Dev. 56.37	Std. Dev. 0.476	Std. Dev. 0.479

The variables that best describe the variation in unit cost of crack sealing are X4, average hours worked per accomplishment, X6, average amount of bituminous sealer used, and X10, the average amount of cover aggregate used. The final model that was used to describe the variation of unit cost in crack sealing was:

$$Y_{ij} = \mu + \beta_0 + \beta_4 X4_{ij} + \beta_6 X6_{ij} + \beta_{10} X10_{ij} + \varepsilon_{(ij)} \quad (A.2.6)$$

This was based on the fact that the least square means for the two models were approximately the same, showing the variable subdistrict does not add appreciably to describing the variation in unit cost of crack sealing. Also the PR > F value of 0.19 given from the GLM procedure indicates that the factor subdistricts could be removed from the model given in Equation A.2.5.

One point that should be made is that the least square means procedure for the model in equation (A.2.6) has confirmed that the α-level given from the Type III sums of square (0.19) is an accurate account of how the variable affects the dependent variable.

A.2.11 Comparison of Original and Adjusted Means

The unadjusted and adjusted (for Equation A.2.6) subdistrict unit cost means were compared. The subdistricts were placed into one of three groups. Those falling above one standard deviation from the grand mean

were placed in one group, those falling below one standard deviation from the grand mean were placed in one group, and those between plus or minus one standard deviation from the grand mean were placed in another group. These groups represent high unit cost, low unit cost, and average unit cost of subdistricts performing crack sealing respectively. These groupings conform to the groupings produced by the MIS [3]. Therefore, a change in subdistrict grouping from before and after adjustment of the means is possible. Figures A.2.18 and A.2.19 show before adjustment and after adjustment groupings of the subdistricts within the state of Indiana.

Table A.2.11 identifies which subdistricts were placed in which group for the unadjusted and the adjusted mean data (adjusted for Equation A.2.6).

A.2.12 Results of Analysis

From the previous analysis discussed above, the variables that describe the variation in unit cost of crack sealing were X4, average hours worked per accomplishment, X6, average amount of bituminous sealer used, and X10, average amount of cover aggregate used. Also it was discovered that when these three variables were used to describe the variation in unit cost, there was no significant difference among subdistricts. This is an indication that all subdistricts perform roughly the

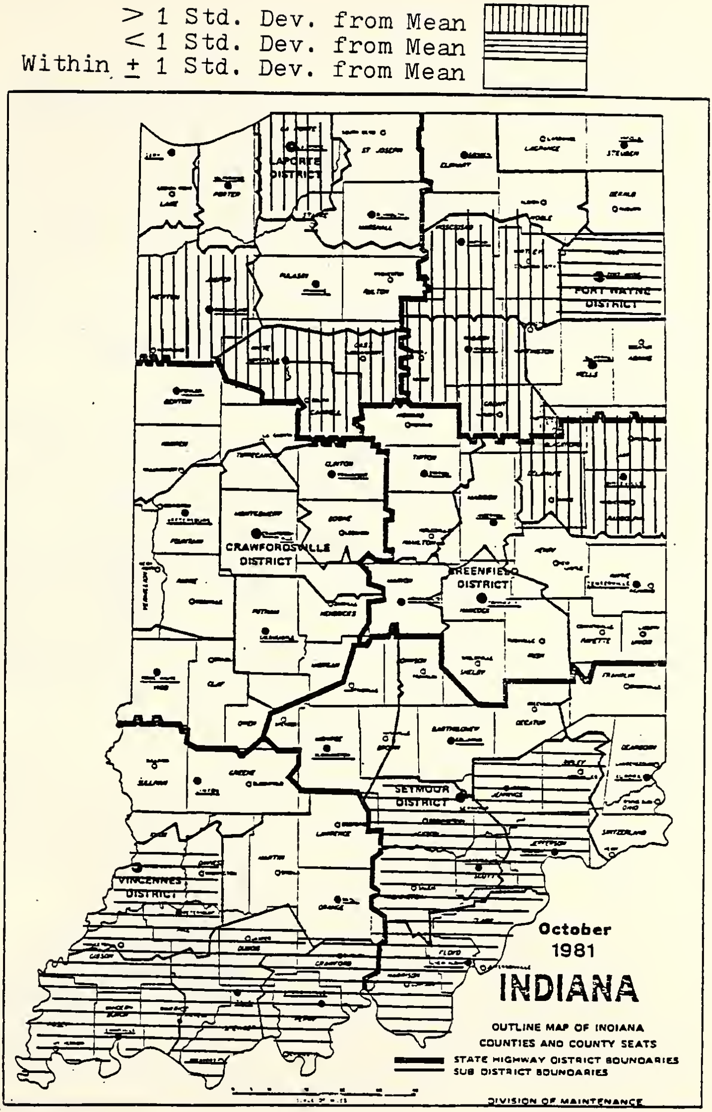

Figure A.2.18 Grouping of Subdistricts Before Adjustment of Means.

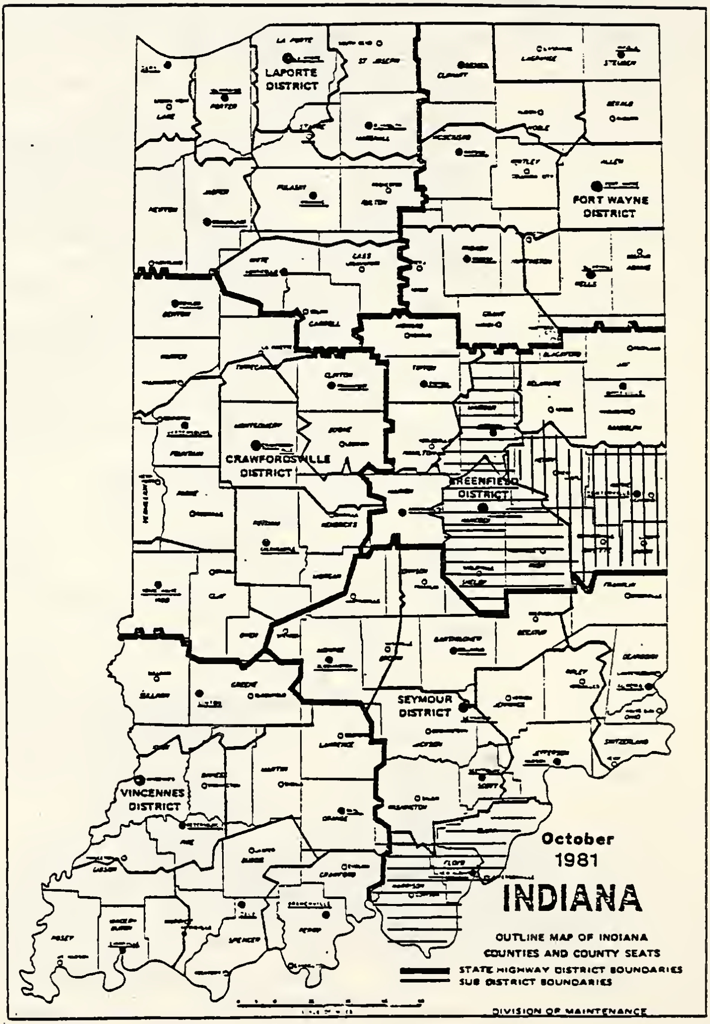

Figure A.2.19 Grouping of Subdistricts After Adjustment of Means.

Table A.2.11 Subdistrict Grouping of Unadjusted and Adjusted Least Squares Means.

Grouping	Subdistricts Unadjusted Means	Subdistricts Adjusted Means
1) Greater Than One Std. Dev. from Mean	5,7,11,18,19,20 22	15
2) Less Than One Std. Dev. from Mean	9,29,30,31,33,34 36,37	14,16,29
3) Within One Std. dev. from Mean	all others	all others

same job when crack sealing, but use differing amounts of materials and labor to do so. If production is to be improved, the areas where the improvements are to be made are in labor practices and material use. Therefore, the areas of concentration during field observations should be labor practices and material use for crack sealing.

A.3 Statistical Analysis of Shallow Patching Data

This section presents the statistical analysis run on the shallow patching data for fiscal year 1983. The analysis using the dependent variable, unit cost of shallow patching (cost/ton of mix applied), was run over two month periods from July 1982 through June 1983 for each of the 37 subdistricts in Indiana. The following 16 covariates were measured simultaneously with the dependent variable (over each 2 month period):

X1. Frequency of application (how often shallow patching was performed in the two month period)

X2. Average accomplishment per tons of mix placed per day of patching

X3. Average crew size per day of patching

X4. Average hours worked per accomplishment

X5. FMS - Bituminous hot mix used

X6. PMS - Bituminous hot mix used

X7. FMS - Bituminous cold mix used

X8. PMS - Bituminous cold mix used

X9. FMS - Salvage bituminous mix used

X10. PMS - Salvage bituminous mix used

X11. FMS - Asphalt used

X12. PMS - Asphalt used

X13. FMS - Aggregate (coarse)

X14. PMS - Aggregate (coarse)

X15. FMS - Seal/Cover aggregate (sand)

X16. PMS - Seal/Cover aggregate (sand)

where, FMS = fraction of time the material was used (in a two month period)

PMS = average amount of material used per accomplishment or production unit

A.3.1 Factor Interaction

An analysis of variance (ANOVA) was run on the data to determine if an interaction between the two variables, subdistrict and time (2 month periods), existed. Since there was only one observation per cell for this two way classification of the data, the Tukey one degree of freedom for nonadditivity procedure [9] was used. The results of the analysis are given in Table A.3.1.

The interaction term was significant at the α-level equal to 0.05, and therefore there is no generally accepted way to test for normality or homogeneity of variance of the data. With the interaction present, the variable, time (2 month periods), could not be considered random and therefore unit cost of shallow patching was found to be dependent on which two month period was being

Table A.3.1 Results of Tukey One Degree of Freedom for Nonadditivity Testing.

Source	DF	MS	F
Subdistricts	36	1747.2	6.7^{**}
Time	5	2756.8	10.6^{**}
S*T	1	1205.7	4.6^{*}
Residual	179	259.3	

* Significant at = 0.05

** Significant at = 0.01

considered.

The data does not conform to the assumptions of the ANOVA model. That is, the data were found to be non-additive and therefore the tests for normality and homogeneity presented in section A.2 cannot be performed on this data. Therefore the next step in the analysis of this data is to run an analysis of covariance using all the independent variables.

A.3.2 Analysis of Covariance

The next step was to run an analysis of covariance (ANCOV). The dependent variable was unit cost (Y), the independent variables were subdistrict (S), time period (T), and the interaction term (ST), and districts (D) that are made up from specific grouping of subdistricts, and the variables run as covariates were X1 through X16 previously defined.

The initial model that was analyzed was:

$$Y_{ijk} = \mu + D_i + S_{(i)j} + T_k + DT_{ik} + \beta_1 X1_{jk} + \dots + \beta_{16} X16_{jk} + \varepsilon_{ijk} \quad (A.3.1)$$

where:

$i = 1,\dots,6 \quad j = 1,\dots,37 \quad k = 1,\dots,6$

μ = mean

D_i = i^{th} district

$S_{(i)j}$ = j^{th} subdistrict within the i^{th} district

T_k = k^{th} time period

DT_{ik} = interaction term of the i^{th} district and the k^{th} time period

$\beta_1 X1 - \beta_{16} X16$ = covariates previously defined

ε_{ijk} = error term

The results of this analysis are given in Table A.3.2. From this analysis it was found that the variables D, T, DT, X1, X2, X3, X6, X8, X10, X11, X15 and X16 were not significant in describing the variation of unit cost of shallow patching. That is, they did not affect unit cost. The variables that best describe that variation in unit cost were found to be subdistrict, X4, X5, X7, X12 and X13.

The model that was run to reach this conclusion was:

$$Y_{ij} = \mu + S_i + T_j + ST_{ij} + \beta_1 X1_{ij} + \ldots + \beta_{16} X16_{ij} + \varepsilon_{(ij)} \qquad (A.3.2)$$

The results of this analysis are given in Table A.3.3 (Mean Square (MS) based on TYPE III sums of squares). An interesting finding of this analysis was that the variable, time (T) and the interaction term, subdistrict by time (ST), were found not to be significant at the 0.05 α-level and need not be considered when the subdistrict

Table A.3.2 Analysis of Variance Table for Equation A.3.1.

Source	DF	Type III SS	F Value	PR F
Districts	5	16.357	1.46	0.20
S(D)	31	111.971	1.61	0.03
Time (T)	5	6.388	0.57	0.72
D*T	25	59.977	1.07	0.38
X1	1	0.052	0.02	0.87
X2	1	0.556	0.25	0.61
X3	1	7.080	3.15	0.07
X4	1	18073.584	8044.92	0.00*
X5	1	161.675	71.96	0.00*
X6	1	6.759	3.01	0.08
X7	1	152.054	67.68	0.00*
X8	1	0.573	0.26	0.61
X9	1	9.901	4.41	0.03*
X10	1	0.262	0.12	0.73
X11	1	1.236	0.55	0.45
X12	1	31.990	14.24	0.00*
X13	1	100.133	44.57	0.00*
X14	1	9.623	4.28	0.04*
X15	1	3.197	1.42	0.23
X16	1	2.576	1.12	0.29
Residual	136	350.535	2.25	

* Significant at = 0.05

Table A.3.3 Analysis of Variance Table for Equation A.3.2.

Source	DF	MS
S	36	3.47
T	5	2.09
S*T	1	0.67
X1	1	0.06
X2	1	0.17
X3	1	8.94
X4	1	20,582.11*
X5	1	190.07*
X6	1	2.18
X7	1	183.08*
X8	1	0.19
X9	1	6.12
X10	1	0.30
X11	1	2.45
X12	1	31.71*
X13	1	114.89*
X14	1	7.96
X15	1	5.99
X16	1	4.19
Residual	160	2.28

* Significant at = 0.05 and should be retained in the model.

means are adjusted by the covariates X4, X5, X7, X12 and X13. This indicates that the variation found in unit cost of shallow patching is explained by the five covariates and the variable, subdistricts. The variable, time, and the interaction term, ST, do not appreciably account for the variation of unit cost when the other variables are added to the analysis. Removing the variable, time, and the interaction term, ST, the model was now of the form:

$$Y_{ij} = \mu + S_i + \beta_4 X4_{ij} + \beta_5 X5_{ij} + \beta_7 X7_{ij} + \beta_{12} X12_{ij} + \beta_{13} X13_{ij} + \varepsilon_{(ij)} \qquad (A.3.3)$$

The next step of the analysis was to determine if any of the covariates, X4, X5, X7, X12 or X13 do not conform to the assumptions of the ANOVA model. The next four sections describe the various tests used to determine which variables should be used to describe the variation of shallow patching unit cost.

A.3.3 Maximum Stepwise Regression

A maximum stepwise regression analysis (MAXR SAS program) [8] was performed on the remaining covariates to determine if a model with fewer covariates could be achieved. This program (MAXR) allows nearly all possible regressions to be run efficiently. The criterion for judging the regression was the use of the C_p value [5]. The C_p value compares residual sums of squares of the

possible regressions with the residual sums of squares for the model given in Equation A.2.3. The lowest C_p value obtained was when the all five covariates were included in the regression model. Also, the mean square error was the smallest when all five covariates were included in the model.

A.3.4 Correlation Analysis

A correlation analysis was run on all the variables originally discussed in ection A.3.1, however only the six variables given in Equation A.3.3 were of interest and were compared. Again, the variables given in Equation A.3.3 had to be independent of one another to conform to the assumptions of the ANOVA model. Table A.3.4 contains the results of the analysis produced. The measure of correlation used was the correlation coefficient (r) and those variables compared that have a high (r) value are suspect to being non-independent. It was found that X5 and X7 are highly correlated with an (r) value equal to 0.95. One or both of these variables had to be removed from the model to avoid the problem of multi-collinearity [5], after further testing was performed. All other correlation coefficients among variables tested were found to be relatively small and present no problem in the analysis. An interesting result of the correlation analysis was that there was such a high correlation

Table A.3.4 Correlation Matrix of the Variables Included in the Analysis.

	Y	S	M	X4	X5	X7	X12	X13
Y	1.000	-.094	-.151	.994	-.049	.042	.025	.066
S		1.000	----	-.080	-.047	.023	-.103	-.030
M			1.000	-.164	.328	-.297	-.051	-.104
X4				1.000	-.062	.042	.011	.064
X5					1.000	-.946	-.284	-.209
X7						1.000	.156	-.043
X12							1.000	.433
X13								1.000

between unit cost (Y) and average hours worked (X4). The correlation coefficient between these two variables was 0.9944. Such a high correlation between the two variables was expected because of the production unit used to measure unit cost. Unit cost of shallow patching is dollars per ton of mix applied. This unit cost was determined from labor and material costs. Material costs are fixed and do not vary per ton applied, however, labor costs are variable per ton of mix applied and account for most of the cost of shallow patching.

A.3.5 Linearity of Covariates

An analysis was performed to check on the linearity of the covariates remaining in the model, X4, X5, X7, X12 and X13. Each variable was plotted against the dependent variable, unit cost, and judged to see whether the plot was of linear form. Figures A.3.1 through A.3.5 contain the plots for X4, X5, X7, X12 and X13 against Y respectively. From the figures, it was found that only one variable, X4, was a linear form and therefore, conformed to the assumptions of the analysis.

A.3.6 Homogeneity of Slopes

A test for the homogeneity of slopes for the independent variables was performed to determine whether

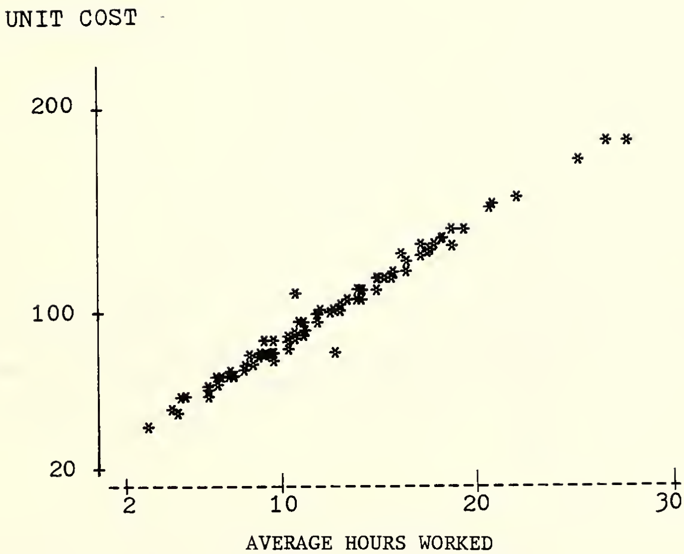

Figure A.3.1 Plot of Unit Cost vs. Average Hours Worked (X4).

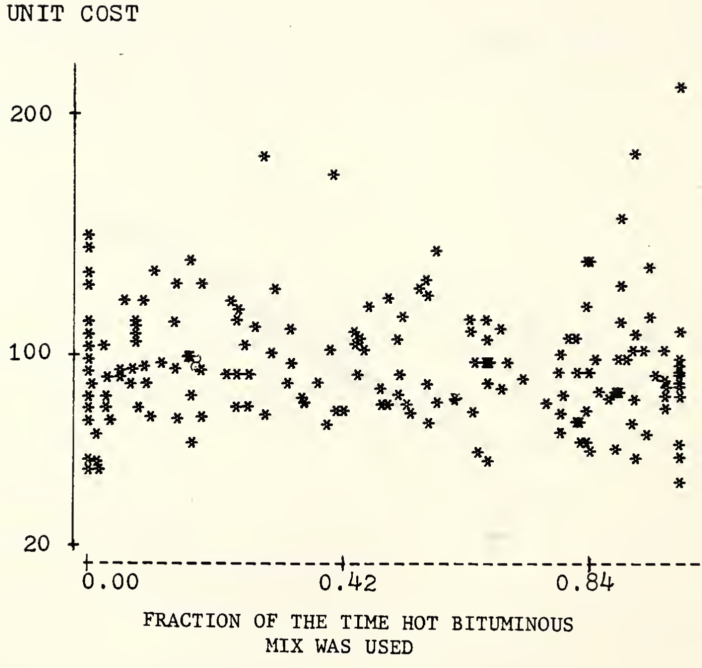

Figure A.3.2 Plot of Unit Cost vs. Fraction of the Time Hot Bituminous Mix was Used (X5).

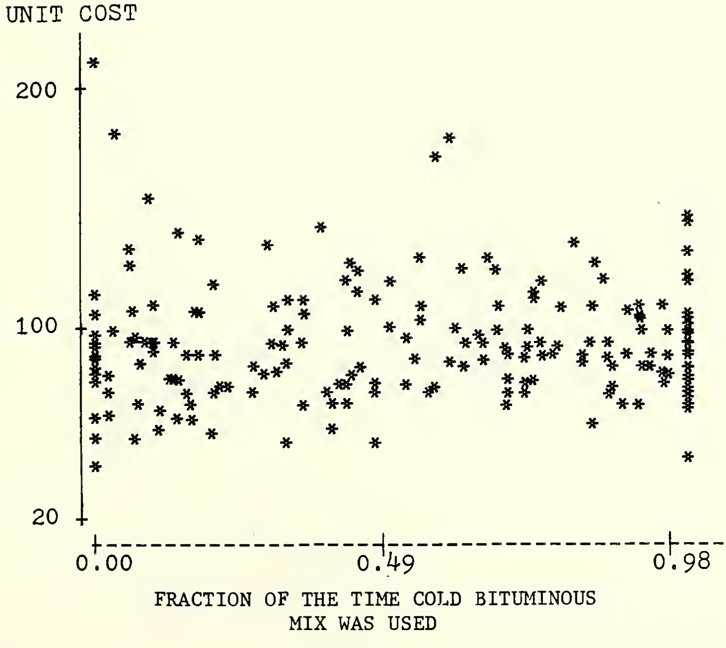

Figure A.3.3 Plot of Unit Cost vs. Fraction of the Time Cold Bituminous Mix was Used (X7).

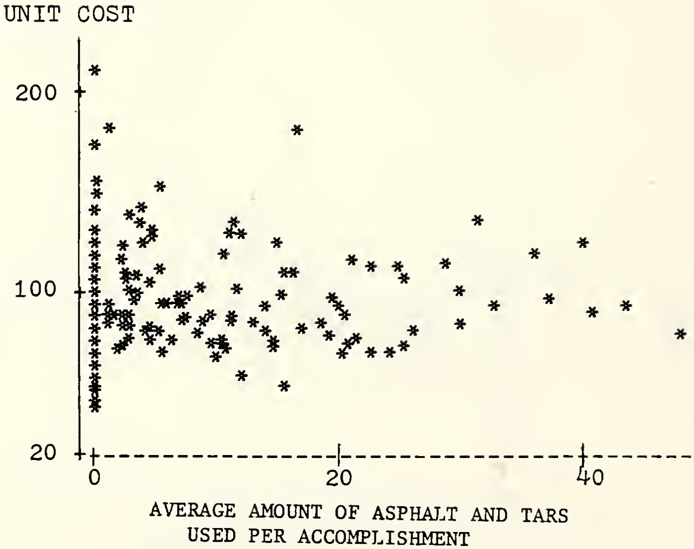

Figure A.3.4 Plot of Unit Cost vs. Average Amount of Asphalt and Tars used per Accomplishment (X12).

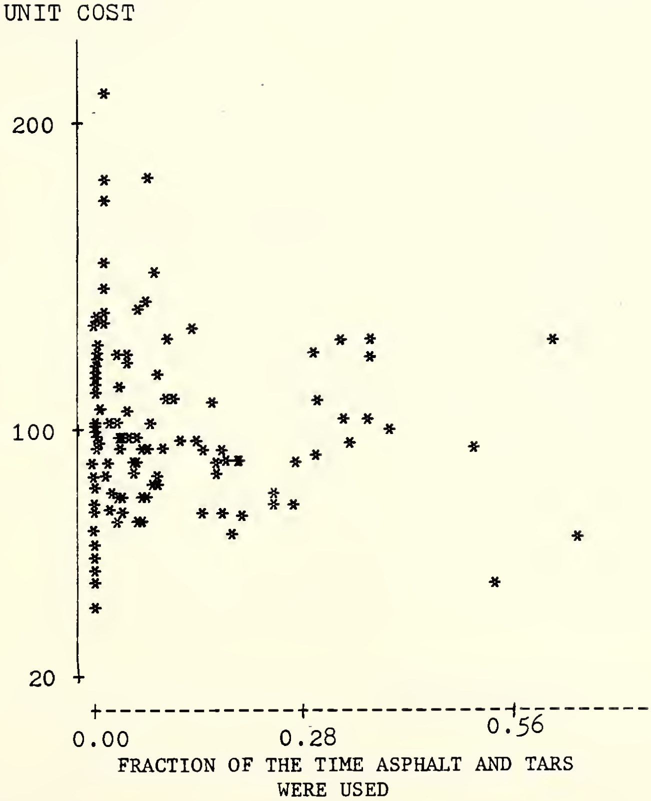

Figure A.3.5 Plot of Unit Cost vs. Fraction of the Time Ashpalt and Tars were used (X13).

the slope of the β coefficient for each subdistrict (1 through 37) was the same. The results of this test are given in Table A.3.5. The following model for each covariate was used to determine if all subdistricts have the same relationship with the covariate. This model was run for each of the five covariates:

$$Y_{ij} = \mu + S_i + X_i + SX_i + \varepsilon_{ij} \qquad \text{(A.3.4)}$$

where, X_i = X4, X5, X7, X12, X13

If in the analysis of variance the SX_i term turns out insignificant (PR > F value greater than 0.05), then the covariate has equal β coefficients for all subdistricts. If PR > F values are small, then this is an indication that there is an interaction among S and X and that the slopes vary among subdistricts. The test showed that covariates X4 and X13 have equal slopes. However, X5, X7 and X12, all had PR > F values less than 0.01 and therefore should be removed from the model.

A.3.7 Reduced Model

From the previous testing, the two variables that should remain in the model are subdistricts (S) and average hours work per accomplishment (X4). These two variables are both significantly important in describing the variation of unit cost of shallow patching as well as meeting the assumptions of the ANOVA model. The reduced

Table A.3.5 Results of the Homogeneity of Slopes Testing.

Variable	Source	DF	PR F
X4	S*X4	36	0.8169
X5	S*X5	36	0.01
X7	S*X7	36	0.01
X12	S*X12	36	0.01
X13	S*X13	36	0.2216

model is of the form:

$$Y_{ij} = \mu + S_i + X4_i + \varepsilon_{ij} \qquad (A.3.5a)$$

An analysis of covariance was performed on the model given in Equation A.3.5a. The results of this analysis are given in Table A.3.6. The analysis showed that the variable subdistrict was not significant in explaining the variation of unit cost and was therefore removed from the model. The variable no longer describes the variation found in unit cost with the covariates X5, X7, X12 and X13 removed from the model. Average hours worked accounts for the variation in unit cost of shallow patching. This agrees with the high correlation coefficient between X4 and unit cost found in section A.3.6. The model is now of the form:

$$Y_{ij} = \mu + X4_i + \varepsilon_{ij} \qquad (A.3.5b)$$

A.3.8 <u>Normality of the Residuals</u>

A test for normality of the residuals was performed by obtaining the residuals of the regression model:

$$Y_{ij} = \mu + X4_i + X17_i + \ldots + X52_i + \varepsilon_{ij} \qquad (A.3.6)$$

The residuals were then tested using the Kolmogorov - Smirnov (KS) test [10] for W > 50. In this case, the number of observations were 222, however, a conservative test was desired so the number of observations (n) used to

Table A.3.6 Analysis of Variance Table for Equation A.3.5a.

Source	DF	Type III SS	F Value	PR F
S	36	268.76	1.24	0.18
X4	1	60301.15	10006.61	0.00
Residual	184	1108.81		

calculate the KS D-critical was 222 minus 36 (indicator variables) or 184. The Kolmogorov-Smirnov D-critical value was calculated by:

$$\text{for } \alpha = 0.01, \quad \frac{1.63}{\sqrt{n}}$$

$$\text{for } \alpha = 0.05, \quad \frac{1.36}{\sqrt{n}}$$

Using the 184 observations, the D-critical values calculated were 0.100 and 0.120 for α equal to 0.05 and 0.01, respectively. The observed D-calculated value was 0.2136. Since the observed D-calculated value was greater than the D-critical values, normality of the residuals was rejected. The residuals obtained were plotted and are shown in Figure A.3.6. From the plotted residuals, it was found that there were two points that were extremely large. These points were the residuals for subdistrict 37 at time period 2 and for subdistrict 15 at time period 5. When reviewing the data set it was found that subdistrict 37 at time period 2 (March-April, 1983) had a mean cost of 80.374 dollars/accomplishment while having an average hours per accomplishment of 13.1. The recorded cost is much too low for the recorded hours worked. The average unit cost of other subdistricts recording 13.1 average hours per accomplishment was approximately 104 dollars.

Subdistrict 15 at time period 5 (Sept.-Oct., 1982) recorded 109.946 dollars for unit cost and 11.0 average

```
          -17 * S37,T2(1)                                                        1
          -16                                                                    0
          -15                                                                    0
          -14                                                                    0
          -13                                                                    0
          -12                                                                    0
          -11                                                                    0
          -10                                                                    0
          - 9                                                                    0
          - 8                                                                    0
          - 7                                                                    0
          - 6 *                                                                  1
          - 5 **                                                                 3
      R   - 4 **                                                                 3
      E   - 3 ***                                                                5
      S   - 2 ***                                                                5
      I   - 1 **************                                                    35
      D     0 ******************************************** 111
      U     1 ***************                                                   37
      A     2 ******                                                            11
      L     3 ***                                                                5
      S     4 *                                                                  2
            5 *                                                                  2
            6                                                                    0
            7                                                                    0
            8                                                                    0
            9                                                                    0
           10                                                                    0
           11                                                                    0
           12                                                                    0
           13                                                                    0
           14                                                                    0
           15                                                                    0
           16                                                                    0
           17 * S15,T5(2)                                                        1
              ______________________________________________________________
                          25          50          75          100
                                    FREQUENCY
```

Where:

1 S37,T2 means Subdistrict 37
Time Period 2 (March,April)

2 S15,T5 means Subdistrict 15
Time Period 5 (Sept.,Oct.)

Figure A.3.6 Plot of Residuals vs. Frequency.

hours per accomplishment. In this case, the recorded unit cost is too high for the recorded average hours per accomplishment. The average unit cost of the other subdistricts that record 11 hours, for average hours worked per accomplishment, was approximately 90 dollars. Due to this inconsistency it was found that some of the data must have been incorrectly transferred from the crew day cards to the data tape or were recorded incorrectly in the field onto the crew day cards. No satisfactory adjustment of the data was possible. Since the symmetry of the residual frequency plot was of the correct form for a normal distribution, the residuals for the unadjusted data were obtained and tested for normality using the Kolmogorov-Smirnov test. The residuals obtained from the unadjusted data had an observed Kolmogorov-Smirnov D-calculated value of 0.0682. Since this value was less than the D-critical value (0.100 at α = 0.05), normality of the distribution was accepted.

The two points in question were not removed from the data base because they are mean values for a 2-month time period. If removed, all information on the two subdistricts would be lost. There was no possible way to determine which of the data recordings were inaccurately recorded on the crew day cards or the data tape because the MIS calculates average costs from the information provided on the data tape. That is, no cost per day is

recorded on the tape and the only way of determining which records are wrong is to calculate the cost for each crew for every day by hand. The data tapes are over 10,000 records long and therefore, the time necessary to review each record was not justified for the amount of information that would have been gained.

A.3.9 Least Squares Adjustment of Means

The least squares means were obtained to determine how well the variable, X4, accounts for the variation of the unit cost of shallow patching. If the variance of the means are small after adjustment, then the variable, X4, accounts for the variation of unit cost. To obtain the least squares adjusted means for the model given in Equation A.3.5a, the coefficient of the independent variable X4 must be obtained. The coefficient was obtained through a stepwise regression procedure [7]. The coefficient obtained is given in Table A.3.7. The least squares adjusted means, adjusted for the model given in Equation A.3.5b, were obtained for subdistricts and were compared with the original subdistrict means. Table A.3.8 contains both adjusted and unadjusted subdistrict means. The comparison of the means shows how well the reduced model (Equation A.3.5b) accounts for the variation of unit costs.

Table A.3.7 Regression Coeficients of the Variables Included in the Equation A.3.5a.

Source	Beta-value	Std. Error	C(P)
Intercept	25.562		2.00
X4	5.831	0.042	

Table A.3.8 Unadjusted and Adjusted Least Squares Means.

Unadjusted Means Subdistrict No.	Mean	Adjusted Means Subdistrict No.	Mean
16	141.53	5	98.76
2	130.18	1	98.41
13	122.51	36	97.88
5	121.37	12	97.82
4	118.89	7	97.63
32	117.27	11	97.63
17	116.55	33	97.49
33	108.30	20	97.47
28	106.17	21	97.33
36	105.17	35	97.19
30	101.43	6	97.17
15	100.30	9	97.16
35	98.83	13	97.07
22	96.82	23	96.91
11	95.86	14	96.85
34	95.28	26	96.84
14	95.27	17	96.77
37	94.78	8	96.68
7	94.40	18	96.67
20	94.23	22	96.64
29	94.23	4	96.57
12	93.03	25	96.55
21	92.92	27	96.52
3	92.13	37	96.52
25	91.56	29	96.49
19	91.37	28	96.43
1	91.27	34	96.27
6	90.13	32	96.22
10	86.65	24	96.07
26	85.51	19	96.07
23	78.85	10	95.93
24	78.11	2	95.87
9	76.37	15	95.47
18	74.42	31	95.46
8	72.67	16	95.22
31	72.67	30	95.21
27	61.30	3	95.08

$Y \pm S_Y$: 96.7 ± 18.22 $\qquad$ 96.7 ± 0.75

68% range : 78.48 - 114.92 $\qquad$ 95.95 - 97.45

As shown in Table A.3.8, the variation in unit cost has been greatly reduced from a spread, in unit cost, of approximately 80 dollars found in the unadjusted means, to a spread, in unit cost, of approximately 6 dollars in the adjusted means.

A Duncan pairwise comparison [7] was run on the adjusted means and an α-level of 0.05 was used for this test. This test allows investigation of differences between all possible pairs of means, however, the basis of the grouping of subdistricts was done by plus or minus one standard deviation of the grand mean 96.70. From the Duncan test, it was found that subdistrict 5 was statistically different than subdistrict 3 but all other subdistrict pair or means were not statistically different.

The grouping of the subdistricts before and after adjustment means are given in Table A.3.9, and are also shown on Indiana maps, Figures A.3.7 and A.3.8. Only subdistrict 5 remains in the high cost group after adjustment of the mean and only subdistrict 31 remained in the low cost group. The changes in grouping of particular subdistricts from unadjusted to adjusted means was due only to the labor (average hours worked per accomplishment), X4, variable.

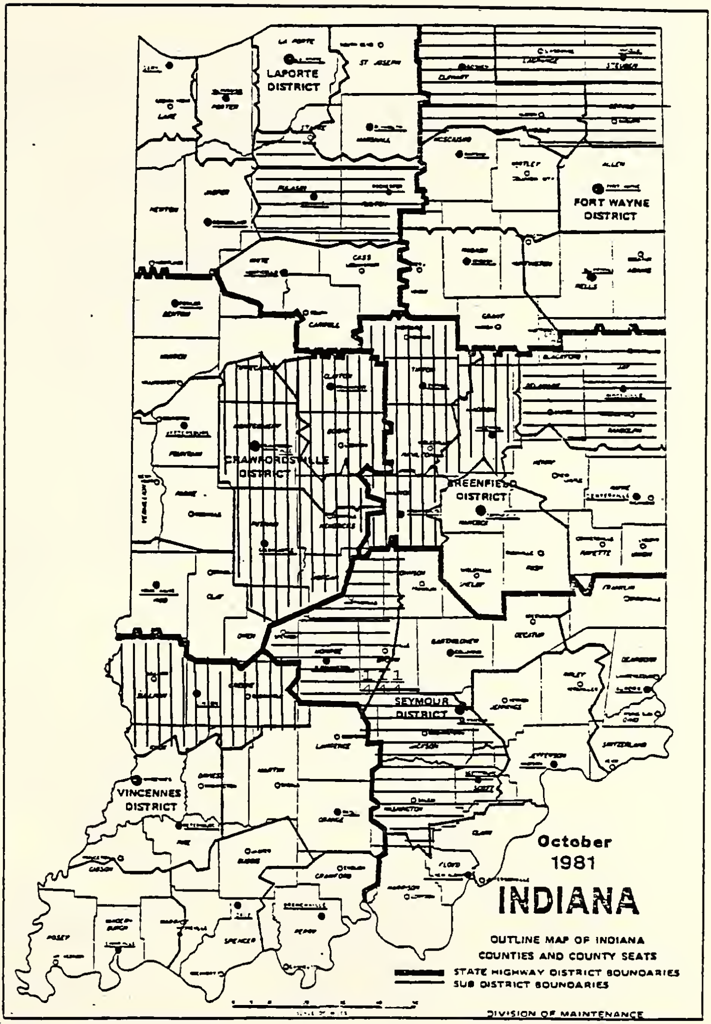

Figure A.3.7 Grouping of Subdistricts Before Adjustment of Means.

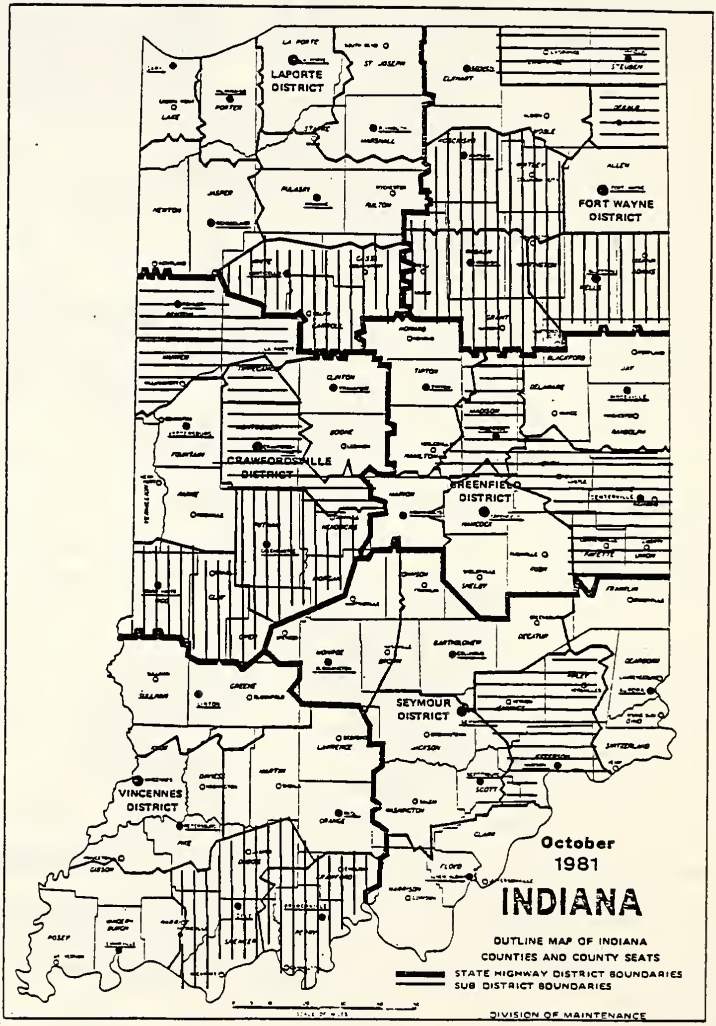

Figure A.3.8 Grouping of Subdistricts After Adjustment of Means.

Table A.3.9 Subdistrict Groupings Before and After Adjustment of Means.

Grouping	Subdistrict Unadjusted Means	Subdistrict Adjusted Means
1) Greater Than One Std. Dev. from Mean	16,2,13,5,4,32 17	5,1,36,12,7,11 33,20
2) Less Than One Std. Dev. from Mean	24,9,18,8,31,27	10,2,15,31,16 30,3
3) Within One Std. Dev. from Mean	all others	all others

A.3.10 <u>Conclusions</u>

From the statistical analyses performed on the shallow patching data, it was first discovered that there was an interaction of the variables, subdistrict and time, when an analysis of variance was run on the data. The analysis revealed that there is a difference in unit cost among subdistricts for a given time period, and differences in unit cost for one subdistrict for different time periods. Also, since the interaction term was significant, no test for parts of the ANOVA model assumptions were possible. When the covariate variables (X1 - X16) were included in the analysis, it was found that time periods and the interaction between variables, subdistrict and time, were not significant to the analysis. That is, there was no statistical difference in unit cost among months or the interaction of subdistricts and months. Also, it was found that there was no difference in unit cost among districts. The variable that was found to be significant to the analysis was average hours worked per accomplishment (X4).

The final results of the analysis showed that the difference in unit cost of shallow patching among subdistricts and the variation was due to labor. Therefore, labor and labor practices (and any factor that may affect labor) were carefully examined during the field observations.

Appendix 2 Tukey One Degree of Freedom for Nonadditivity Written in SAS Language.

```
DATA A1;
INPUT A 1 B 2 Y 3-5;
K=1;
CARDS;
PROC SORT DATA=A1; BY A:
PROC MEANS DATA=A1 NOPRINT; BY A;
VAR Y;
OUTPUT OUT=A2 MEAN=MYA;
DATA A3; MERGE A1 A2; BY A;
PROC SORT DATA=A3; BY K B;
PROC MEANS DATA=A3 NOPRINT; BY K B;
VAR Y;
OUTPUT·OUT= A4 MEAN=MYB;
DATA A5; MERGE A3 A4; BY K B;
PROC MEANS DATA=A5 NOPRINT; BY K;
VAR Y;
OUTPUT OUT=A6 MEAN=MY;
DATA A7; MERGE A5 A6; BY K;
X=(MYA-MY)*(MYB-MY);
PROC PRINT DATA=A7;
PROC GLM DATA=A7;
CLASSES A B;
MODEL Y=A B X;
```

Appendix 3 SAS Program to Obtain Least Squares Adjusted Means for a Regression Model

```
DATA DDD;
INPUT Y  X4 X6 X10;
IF M=3 THEN DELETE;
IF M=4 THEN DELETE;
IF Y=.000 THEN DELETE:
KK=1;
BB=5.82305987;
CC=0.77957546;
DD=2.99226478;
PROC SORT DATA=DDD; BY KK:
PROC MEANS DATA=DDD NOPRINT; BY KK;
VAR X4;
OUTPUT OUT=B MEAN=MX4;
DATA C; MERGE DDD B; BY KK;
PROC MEANS DATA=C NOPRINT; BY KK;
VAR X6;
OUTPUT OUT=D MEAN=MX6;
DATA E; MERGE C D; BY KK;
PROC MEANS DATA=E NOPRINT; BY KK;
VAR X10;
OUTPUT OUT=F MEAN=MX10;
DATA G; MERGE E F; BY KK;
PROC SORT DATA=G; BY S;
PROC MEANS DATA=G NOPRINT; BY S;
VAR X4;
OUTPUT OUT=H MEAN=MX4S;
DATA I; MERGE G H; BY S;
PROC MEANS DATA=I NOPRINT; BY S;
VAR X6;
OUTPUT OUT=J MEAN=MX6S;
DATA K; MERGE I J; BY S;
PROC MEANS DATA=K NOPRINT; BY S;
VAR X10;
OUTPUT OUT=L MEAN=MX10S;
DATA M; MERGE K L; BY S;
PROC MEANS DATA=M NOPRINT; BY S;
VAR Y;
OUTPUT OUT=N MEAN=MYS;
DATA O; MERGE M N; BY S;
X=MYS-(BB*(MX4S-MX4))-(CC*(MX6S-MX6))-(DD*(MX10S-MX10));
PROC SORT DATA=O; BY X;
PROC PRINT DATA=O;
```

Appendix 4 Questionnaire Sent to All Subdistricts.

- 1 -

1) What percentage of the pavements for which you are responsible are:

Approximate Percentage

a) Full Depth Asphalt ______

b) P.C. Concrete

(1) CRC ______
(2) Jointed ______

c) Overlay (Resurfaced)

(1) Asphalt over asphalt ______
(2) Asphalt over concrete ______

2) What percentage of the roads for which you are responsible are:

Approximate Percentage

a) Interstate ______

b) Other State Highways

(1) Multilane ______
(2) Two Lane ______

3) On an annual basis, what percentage of shallow patching do you perform on:

Approximate Percentage

a) Interstate ______

b) Other State Highways ______

(1) Multilane ______
(2) Two Lane ______

4) How much time does it take, on the average, for your crew to go from the garage where the equipment is located to the job site to begin shallow patching or crack sealing?

a) Shortest Time ________

b) Longest Time ________

5) What are the possible reasons for the time differences recorded in 4) above?

1.

2.

3.

4.

6) From which plants do you most often pick up the bituminous material used in shallow patching and crack sealing?

a) Shallow Patching (activity 201)

1. ____________________
2. ____________________
3. ____________________

b) Crack Sealing (activity 207)

1. ____________________
2. ____________________
3. ____________________

7) What causes the most delay in shallow patching work for your subdistrict?

8) What causes the most delay in crack sealing work for your subdistrict?

- 3 -

9) What percentage of the time does a unit foreman accompany a crew assigned to the task of shallow patching and crack sealing?

	Approximate Percentage
a) Shallow Patching	________
b) Crack Sealing	________

10) On the average, how much time in advance do you schedule shallow patching in your subdistrict?

11) On the average, how much time in advance do you schedule crack sealing in your subdistrict?

12) Do you use any measure(s) to evaluate the quality of the shallow patching and crack sealing work done by the crews in your subdistrict?

YES _____ NO _____

If yes, please indicate the measures below:

Shallow Patching

1.
2.
3.
4.

Crack Sealing

1.
2.
3.
4.

13) Is there a day to day difference in equipment used for shallow patching and/or crack sealing or does your subdistrict use a specific grouping of equipment for each and every site?

Shallow Patching:

Crack Sealing:

14) If a specific set of equipment is used for either activity, please list the individual pieces of the equipment.

Shallow Patching:

Crack Sealing:

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